# TECHNOLOGY PROFILE:

# RESIDENTIAL GREYWATER HEAT RECOVERY SYSTEMS

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# TECHNOLOGY PROFILE SUMMARY
# RESIDENTIAL GREYWATER HEAT RECOVERY SYSTEMS

## INTRODUCTION

This report is a Technology Profile on residential greywater heat recovery (GWHR) systems. It provides an overview of the historical and current activities in the field and also offers some insights into the future directions which the technology might take, both from a technical perspective and with respect to commercialization. The Profile specifically includes:

- A background review of residential hot water consumption patterns, usage characteristics and the technology currently used for hot water heating systems.
- A generic description of the various types of residential GWHR systems and the benefits which they produce.
- A summary of the technical obstacles which GWHR technology faces as well as the hurdles which exist to widespread commercialization.
- A description of commercially available GWHR systems and a discussion of the types of applications to which the technology is best suited.
- An assessment of the potential markets for GWHR systems and how these markets might be successfully developed.

## HOT WATER CONSUMPTION PATTERNS

One of the major conclusions of this study was that the size, and flow characteristics, of the domestic hot water (DHW) load have a significant influence on the technical and economic viability of GWHR systems. Applications which are the most desirable have large hot water loads with flow patterns which closely match the performance capabilities of the GWHR system.

Various researchers have studied residential DHW loads and have reported average, annual gross energy consumption values ranging from 3,770 to 5,760 kWh/yr for electric tanks, and up to 9,195 kWh$_e$/yr for natural gas water heaters. Manitoba Hydro's own estimate for its customer base (3,770 kWh/yr) is at the low end of this range, likely due to the smaller family size in their sample. With respect to the flow characteristics of the DHW load, hot water end-uses can be characterized as being either batch or simultaneous flow loads. Based on limited (and somewhat dated) research, it was concluded that about 65% of the residential DHW load can be described as a batch flow, i.e. in which the potable water and greywater flows do not occur at the same time (such as a bath, dishwasher or washing machine). The remaining 35% can be characterized as a simultaneous flow load in which the two fluid streams are concurrent (e.g. a shower). However, these average values can vary widely for individual houses.

## TYPES OF RESIDENTIAL GREYWATER HEAT RECOVERY SYSTEMS

Residential GWHR systems can be broadly classified into four distinct types:

- Combined storage tank/heat exchanger type which uses thermal conduction and convection to transfer heat between the greywater and potable water
- Combined storage tank/heat pump type which uses a heat pump to facilitate the heat transfer process
- Non-storage type which does not use thermal storage and connects directly into the house's drain/waste/vent stack
- Point-of-use type which is incorporated directly into an end-use device, such as a shower, and consists of a heat exchanger but no thermal storage

The first two types of systems are able to recover heat from both batch loads and simultaneous flow loads whereas the last two can only recover appreciable amounts of energy from simultaneous flow loads.

## BENEFITS

There are several benefits which a GWHR system can provide to a homeowner, or to a utility which is supplying energy for the DHW heater:

- Energy savings
- Increased First-Hour Rating of the tank
- Improved comfort due to slower temperature degradation at run-out
- Reduction of the coincident, peak demand
- Possible elimination of one tank in an otherwise dual-tank system

## TECHNICAL OBSTACLES

There are a number of potential technical obstacles which residential GWHR systems have to overcome including:

- Controlling the overall system cost
- Possible need for segregated plumbing
- Physical size, lost floor space and the need to be located below the greywater source(s)
- Maintenance requirements
- Possibility, and perception, of contamination
- Temperature control of the domestic hot water at the end-use

Of all the potential obstacles, controlling system costs, and minimizing or eliminating maintenance requirements were judged as the most important and which had the greatest opportunity to impede adoption of GWHR technology.

## OBSTACLES TO COMMERCIALIZATION OF THE TECHNOLOGY

There are also a number of market-based obstacles which stand in the way of large-scale commercialization of GWHR technology:

- Lack of market awareness
- Limited performance data
- Perceived cost effectiveness
- Health and safety concerns
- Possible opposition by building officials
- Absence of testing and product standards

## CURRENT COMMERCIAL ACTIVITIES

Five firms were identified who are presently marketing residential GWHR systems or are attempting to enter the marketplace. One, an established manufacturer of hot water tanks, is now in large-scale production while the remaining four firms are attempting to bring their products into full production.

## APPLICATIONS

Another important finding of this study was that selection of the proper application is as important as the design of the GWHR product or system which is chosen to meet the application. The characteristics of a good application were identified as:

- Expensive DHW energy source
- High DHW consumption
- Poor water heater efficiency
- Large family size
- Limited opportunity for hot water conservation
- Need for two DHW tanks
- Willingness of the family to adopt a new technology
- Applications where demand control is important
- Applications where multiple households use common greywater plumbing

## MARKETING THE TECHNOLOGY

The Profile also concluded that marketing strategies developed for GWHR systems should emphasize the benefits which the product provides rather than its features (i.e. the technology). In addition, promotion of the benefits should focus on the comfort, convenience and lifestyle advantages of a GWHR system rather than on the economics (e.g. "more hot water at no extra cost"), even though the economics may be attractive for many applications. It is critical that marketing strategies not fall into the "payback trap" argument, in which decisions are made by the consumer using a simple (and often simplistic) cost recovery basis.

## POTENTIAL MARKETS

Several potential markets were identified which might be successfully exploited by residential GWHR technology. R-2000 houses are a prime candidate, mainly because of the high level of awareness about energy-related issues among their builders and homebuyers. Although the R-2000 market is relatively small, it has a high profile. The second market is multi-unit residential buildings such as duplexes, condominiums and small apartments blocks, particularly those in which dwelling units are stacked vertically and the energy flux of the greywater is much higher than in a detached house.

The third potential market for the technology is electric utilities who could use GWHR systems in their Demand Side Management programs or who may wish to compete more aggressively with natural gas or oil for the hot water heating customer. For example, it was found that the combination of a high efficiency, electric water heater coupled with a GWHR system could, in some cases, be cost competitive from a delivered-energy perspective with natural gas systems due to the inherent efficiency of the electric tank/GWHR combination and the relatively low efficiency of conventional gas water heaters. The electric tank/GWHR combination could also compete very effectively against higher efficiency combustion water heaters because the latter tend to have significantly higher costs, relative to conventional tanks, even though their performance is only marginally better (unless the most sophisticated, and expensive, type of water heater is used). The fourth potential market for GWHR technology is those remote locations which have very high energy costs. However, reliability and the need for low maintenance are very critical issues in these locations.

## ACTION PLAN

The present knowledge base on the performance, costs and practical considerations of GWHR system technology is very limited. These information gaps need to be filled, particularly from the perspective of potential users, such as Manitoba Hydro, who stand to benefit from the technology. The following recommendations are offered as an initial framework for the development of an expanded knowledge base:

1. **Conduct a workshop on GWHR systems for interested parties.**
   A workshop on residential GWHR system technology should be organized and held to establish a network of organizations and individuals with an interest in the technology; identify potential research needs, development and demonstration initiatives, and; to lay the groundwork for collaborative efforts among interested parties.

2. **Establish a residential GWHR system monitoring and evaluation program.**
   More direct experience and documented performance is needed with GWHR systems. Manitoba Hydro should consider establishing a monitoring program to assess the performance of a small number of systems installed in occupied houses to provide a firmer understanding of system performance, costs, installation issues, impact on lifestyle, etc.

3. **Implement a pilot program to gauge consumer reaction to the technology.**
   Based on the outcome of the monitoring program, Manitoba Hydro should consider implementing a pilot program to incorporate GWHR technology into their "No Worry" water tank rental program.

4. **Evaluate the electric water heater/GWHR system option.**
   If the results of these activities are positive, Manitoba Hydro could explore the electric water heater/GWHR option as a means of competing against natural gas water heating for market share.

5. **Develop design and installation guidelines.**
   Natural Resources Canada, and possibly others, should develop design tools, installation guidelines, etc. for GWHR systems including tools for predicting the savings generated by different systems in various applications.

6. **Develop training programs.**
   A plan should be developed to educate codes officials, builders and consumers about residential GWHR systems, their benefits, potential problems and costs.

7. **Develop a testing standard.**
   A laboratory-based testing standard should be developed which describes procedures for determining the thermal performance, and other performance variables, under standardized and representative conditions. It could be based on earlier work performed by Perlman and Mills using an updated version of their simulated-use test.

8. **Develop a product standard.**
   Once a sufficient knowledge base has been created, a product standard should be developed which addresses minimum requirements for health and safety issues, design techniques, installation procedures, maintenance requirements, etc.

# RÉSUMÉ DU PROFIL TECHNOLOGIQUE APPAREILS DE RÉCUPÉRATION DE LA CHALEUR À PARTIR DES EAUX MÉNAGÈRES

## INTRODUCTION

Le présent rapport constitue un profil technologique des appareils de récupération de la chaleur à partir des eaux ménagères (RCAEM). Il contient au aperçu des activités présentes et passées dans ce domaine, en plus de fournir certains détails sur les futures orientations que pourrait adopter la technologie s'y rapportant, tant d'un point de vue technique que sur le plan de la commercialisation. Le profil recèle, en particulier, les éléments suivants:

- un examen technique des habitudes de consommation domestique de l'eau chaude, les caractéristiques propres à l'utilisation de celle-ci et la technologie actuellement en vigueur dans le cas des appareils de chauffage de l'eau;
- une description générique des divers types d'appareils de RCAEM et des avantages qu'ils procurent;
- un résumé des obstacles techniques auxquels sont confrontés les appareils de RCAEM, de même que la description des lacunes qui empêchent une commercialisation étendue;
- une description des appareils de RCAEM qui sont offerts sur les marchés et un examen sur le genre d'applications qui conviennent le mieux à la technologie s'y rapportant;
- une évaluation des possibilités de commercialisation des appareils de RCAEM et des méthodes de développement fructueux des marchés.

## HABITUDES DE CONSOMMATION D'EAU CHAUDE

Une des principales conclusions de l'étude était que la quantité, ainsi que les caractéristiques de débit, se rapportant à l'utilisation de l'eau chaude domestique influaient d'une manière significative sur la viabilité technique et économique des appareils de RCAEM. Les applications les plus souhaitables offraient de grandes possibilités d'utilisation d'eau chaude, le tout accompagné de modèles de débit qui s'harmonisaient de très près avec les capacités des appareils de RCAEM.

Divers chercheurs qui ont examiné la question de la quantité d'eau chaude domestique utilisée ont signalé que la consommation brute moyenne équivalait, chaque année, à des valeurs s'échelonnant entre 3,770 et 5,760 kWh en ce qui concerne les réservoirs fonctionnant à l'électricité, par rapport à 9,195 kWh au maximum pour les chauffe-eau alimentés au gaz naturel. Les estimations de Manitoba Hydro pour l'ensemble de sa clientèle, soit 3,770 kWh par année, se situent à l'extrémité inférieure de cette échelle, probablement en raison de son échantillonnage se rapportant à des familles moins grandes. En ce qui a trait à l'utilisation de l'eau chaude domestique, on peut la caractériser comme étant discontinue ou simultanée. En se fondant sur des recherches circonscrites (et quelque peu dépassées), il a été conclu que près de 65 % de l'utilisation de l'eau chaude domestique peut se décrire comme étant discontinue, c'est-à-dire que l'eau potable et les eaux ménagères n'interviennent pas au même moment (pour le bain, le lave-vaisselle et la machine à laver, par exemple). Le reste, soit 35 %, peut être caractérisé par une utilisation simultanée, alors que deux courants de fluide peuvent se concurrencer (comme dans le cas des douches). Il n'en demeure pas moins que ces valeurs moyennes peuvent grandement varier d'une maison à l'autre.

## TYPES D'APPAREILS DE RÉCUPÉRATION DE LA CHALEUR À PARTIR DES EAUX MÉNAGÈRES

Globalement, il est possible de classer les RCAEM en quatre types distincts :

- une combinaison de réservoir de stockage et d'échangeur de chaleur qui fait appel à la conduction et à la convection thermiques pour le transfert de chaleur entre les eaux ménagères et l'eau potable;
- une combinaison de réservoir de stockage et de thermopompe qui fait appel à une thermopompe pour faciliter le transfert de chaleur;
- un appareil non destiné au stockage qui ne fait pas appel à un procédé thermique, mais se trouve directement branché au conduit de drain, d'élimination ou d'évacuation de la maison;
- un appareil de service combiné directement à un mécanisme destiné aux utilisateurs, comme une douche, et qui comprend un échangeur de chaleur sans stockage thermique.

Les deux premiers types d'appareil sont aptes à la récupération de la chaleur à partir d'une utilisation continue ou simultanée, alors que les deux derniers ne permettent que la récupération de la chaleur en quantité appréciable à partir d'une utilisation simultanée.

## AVANTAGES

Un appareil de RCAEM peut signifier bien des avantages pour un propriétaire de maison ou une entreprise de service public qui fournit l'énergie nécessaire à un chauffe-eau. En voici la description :

- des économies d'énergie;
- une évaluation dès les premiers instants du réservoir qui s'en trouve favorisée;
- un meilleur confort en raison d'une baisse plus lente des températures en fin de réseau;
- la réduction de la demande simultanée en périodes de pointe;
- l'élimination possible d'un réservoir dans un système qui, autrement, en comporterait deux.

## OBSTACLES TECHNIQUES

Il existe nombre d'obstacles techniques qu'il faut éventuellement éliminer lorsque l'on veut installer des appareils de récupération de la chaleur à partir des eaux ménagères, notamment :

- contrôler le coût global du système;
- répondre à la nécessité éventuelle d'installer une plomberie d'appoint;
- s'adapter à l'envergure matérielle du système, perdre de l'espace et s'assurer un emplacement à un niveau inférieur aux sources d'eaux ménagères;
- répondre aux exigences d'entretien;
- affronter la possibilité, et la perception, d'une contamination;
- contrôler la température de l'eau chaude domestique au moment de son utilisation.

Parmi tous les obstacles éventuels, le contrôle des coûts de système, ainsi que l'atténuation ou l'élimination des exigences au chapitre de l'entretien, ont été jugés comme les plus importants, en plus de présenter le plus de possibilités d'empêcher l'adoption de la technologie reliée aux appareils de RCAEM.

## OBSTACLES À LA COMMERCIALISATION DE LA TECHNOLOGIE CONCERNÉE

Plusieurs obstacles liés aux divers marchés se dressent devant la commercialisation à grande échelle de la technologie entourant les appareils de récupération de la chaleur à partir des eaux ménagères. Il s'agit des suivants :

- le manque de sensibilisation des marchés;
- des données restreintes sur les résultats;
- une rentabilité présumée;
- des préoccupations au chapitre de la santé et de la sécurité;
- une opposition éventuelle de la part des responsables officiels des bâtiments;
- la mise à l'essai inexistante et l'absence de normes relatives aux produits.

## ACTIVITÉS COMMERCIALES ACTUELLES

On a découvert cinq entreprises qui pratiquaient actuellement la mise en marché d'appareils de récupération de la chaleur à partir des eaux ménagères ou qui faisaient des efforts pour pénétrer les marchés. Ainsi, un fabricant établi de réservoirs à eau chaude s'attache à la production à grande échelle de ce genre de dispositifs, alors que les quatre autres entreprises tentent d'en arriver à une production entière.

## APPLICATIONS

Un autre grand résultat de cette étude est l'importance aussi grande de choisir la bonne application que la conception du produit ou de l'appareil de RCAEM choisi pour l'application. Voici les caractéristiques d'une bonne application :

- une source d'eau chaude domestique dispendieuse
- une forte consommation d'eau chaude
- l'efficacité déficiente du chauffe-eau
- une grande famille
- des possibilités restreintes d'économiser l'eau chaude
- le besoin de disposer de deux réservoirs d'eau chaude
- le consentement de la famille à adopter une nouvelle technologie
- des applications où le contrôle de la demande est important
- des applications où les occupants d'habitations multiples recourent à la même plomberie pour les eaux ménagères

## COMMERCIALISATION DE LA TECHNOLOGIE

Le profil fait également état de la conclusion selon laquelle les stratégies de commercialisation mises au point pour les appareils de récupération de la chaleur à partir des eaux ménagères (RCAEM) devraient être axées sur les bénéfices que procure le produit plutôt que sur ses caractéristiques (comme la technologie). D'autre part, la mise en valeur des bénéfices devrait porter principalement sur le confort, l'utilité et le style de vie que procurent les appareils de RCAEM plutôt que sur les aspects économiques (comme offrir plus d'eau chaude sans frais supplémentaires), même si ceux-ci peuvent sembler intéressants dans le cas de bien des applications. Il est essentiel que les stratégies de commercialisation ne s'enlisent pas dans le piège du délai de récupération où les consommateurs prennent leurs décisions en fonction de la simple (et souvent simpliste) récupération des coûts.

## POSSIBILITÉS DE MARCHÉS

Plusieurs possibilités de marchés aptes à l'exploitation fructueuse de la technologie résidentielle de RCAEM ont été relevées. La Maison R-2000 en constitue le principal exemple, en raison, particulièrement, du fort niveau de sensibilisation aux questions reliées à l'énergie de la part de ceux qui la construisent et de ceux qui l'achètent. Même si le marché de la Maison R-2000 est relativement restreint, il offre un grand prestige. Le deuxième marché qui existe est celui des immeubles multi-résidentiels, comme les duplex, les appartements en copropriété et les petits immeubles à appartements, plus particulièrement les habitations superposées verticalement à surfaces invariables où la quantité énergétique fournie par les eaux ménagères est plus élevée que dans les habitations unifamiliales.

Le troisième marché éventuel pour la technologie est représenté par les entreprises de service public d'électricité qui pourraient utiliser les appareils de RCAEM pour la mise en œuvre des programmes de gestion de la demande, ou encore qui désireraient faire une concurrence plus vive aux distributeurs de gaz naturel ou de mazout pour gagner la confiance des consommateurs d'eau chaude. On a, ainsi, découvert que la combinaison d'un chauffe-eau électrique à haut rendement énergétique raccordé à un appareil de RCAEM pouvait, dans certains cas, s'avérer rentable sur le plan de la concurrence avec les systèmes alimentés au gaz naturel, particulièrement en ce qui concerne l'obtention de l'énergie nécessaire, en raison du rendement efficace que permet naturellement ce genre de procédé et celui relativement faible des chauffe-eau classiques fonctionnant au gaz naturel. La combinaison d'un chauffe-eau électrique et d'un appareil de RCAEM peut également permettre de concurrencer avec beaucoup de succès les chauffe-eau à combustion plus efficaces parce que ceux-ci tendent à entraîner la hausse des coûts d'une manière significative par rapport aux réservoirs classiques, même si leur rendement n'est accru que d'une façon marginale (à moins d'avoir recours à un type de chauffe-eau plus dispendieux et plus perfectionné). Un quatrième marché possible pour la technologie de la RCAEM se retrouve dans les endroits éloignés qui présentent des coûts énergétiques très élevés. Dans ces emplacements, il est essentiel de pouvoir se fier aux systèmes d'approvisionnement en énergie et de n'avoir que peu d'entretien à faire.

## PLAN D'ACTION

Actuellement, l'ensemble des connaissances relatives au rendement, aux coûts et aux aspects pratiques de la technologie de RCAEM est très limité. Il faut combler ces lacunes au niveau de l'information, surtout du point de vue des utilisateurs éventuels, tels que Manitoba Hydro qui s'attend à retirer les fruits de la technologie. Suivent ci-après des recommandations formulées à titre de cadre préliminaire en vue de l'établissement d'un ensemble élargi de connaissances :

1. **Organiser un atelier sur les appareils de RCAEM à l'intention des parties intéressées.**
   Il faudrait organiser et tenir un atelier sur la technologie propre aux appareils de RCAEM afin de mettre sur pied un réseau d'organisations et de personnes qui s'intéressent à la technologie; déterminer les besoins éventuels en matière de recherche, ainsi que les activités de développement et de démonstration possibles; établir l'assise d'une collaboration entre les parties intéressées.

2. **Mettre sur pied un programme de surveillance et d'évaluation des appareils de RCAEM.**
Il faut acquérir une expérience plus directe et une évaluation documentée du rendement des appareils de RCAEM. Manitoba Hydro devrait envisager la mise sur pied d'un programme de surveillance pour l'évaluation du rendement d'un certain nombre d'appareils installés dans des maisons occupées, obtenant ainsi la possibilité de présenter un bilan plus clair du rendement, des coûts, des problèmes liés à l'installation, des effets sur le style de vie, etc.

3. **Mettre en œuvre un programme pilote permettant de jauger la réaction des consommateurs face à la technologie.**
En se fondant sur les résultats obtenus dans le cadre du programme de surveillance, Manitoba Hydro devrait envisager la mise en œuvre d'un programme pilote permettant de combiner à son programme de location «sans soucis» de réservoir d'eau la technologie propre à la RCAEM.

4. **Évaluer l'option relative au système combiné chauffe-eau électrique/appareil de RCAEM**
Si le résultat des ces activités s'avère positif, Manitoba Hydro pourrait alors explorer la possibilité du système combiné chauffe-eau électrique/appareil de RCAEM comme moyen de concurrencer sur les marchés le chauffage de l'eau à l'aide d'un appareil au gaz naturel.

5. **Élaborer des lignes directrices se rapportant à la conception et à l'installation**
Ressources naturelles Canada, et peut-être d'autres ministères, devraient élaborer des outils de conception, des lignes directrices portant sur l'installation, etc., relativement aux appareils de RCAEM, et en particulier des mécanismes permettant de prévoir les économies possibles grâce aux diverses applications.

6. **Concevoir des programmes de formation**
Il faudrait mettre au point un plan qui permettrait de faire connaître aux responsables de l'élaboration des codes, aux constructeurs et aux consommateurs les appareils de RCAEM, leurs avantages, les problèmes qu'ils peuvent susciter et les coûts s'y rapportant.

7. **Élaborer une norme de mise à l'essai**
Il faudrait élaborer une norme de mise à l'essai, fondée sur des travaux de laboratoire, qui permettrait de déterminer le rendement thermique, ainsi que d'autres aspects variables du rendement en général, dans des conditions normalisées et représentatives. Cette norme pourrait découler du travail accompli précédemment par la société Perlman et Mills, alors qu'il serait possible d'utiliser une version mise à jour de son test de simulation.

8. **Élaborer une norme relative au produit**
Une fois établie l'assise des connaissances, il faudrait élaborer une norme qui engloberait les exigences minimales en matière de santé et de sécurité, de techniques de conception, de procédures d'installation, d'entretien, etc.

## TABLE OF CONTENTS

# SECTION 1

# TECHNOLOGY PROFILE ON RESIDENTIAL GREYWATER HEAT RECOVERY SYSTEMS

## 1.1 INTRODUCTION

This report is a termed a "Technology Profile", and has been prepared to review the present state of knowledge, the level of development and the current state of commercialization of residential greywater heat recovery (GWHR) system technology, both in Canada and abroad. It is broadly divided into four main areas of interest:

- Technology analysis
- Market analysis
- Action plan
- Conclusions and recommendations

GWHR systems are designed to reduce a house's domestic hot water heating (DHW) load by recovering energy from the wastewater stream and using it to preheat the incoming cold water before it reaches the water heater and/or the hot water distribution system. GWHR systems can take several forms ranging from simple heat exchangers to more complex devices incorporating thermal storage and heat pump heat recovery processes.

While the basic operating principles of GWHR systems are relatively simple, the development of practical products and systems has proven to be somewhat elusive. For many years, the idea of recovering heat from a house's greywater stream has been an enticing concept for researchers, building scientists and lone inventors. Many types of GWHR systems have been developed for commercial and industrial applications, where the loads are larger and their economics of operation are more attractive. Yet comparatively little effort has been directed at the development of products for the residential market. A number of research and demonstration projects have been carried out in Canada, the U.S. and Europe, but until recently there have been few attempts at commercial development.

Despite the historically slow pace of development, there is reason to believe that residential GWHR systems may nonetheless have tremendous potential for saving energy, improving water heating system performance and creating significant economic opportunities. From a commercial perspective, residential GWHR systems are a relative newcomer to the marketplace. The first commercially available system, which reached the marketplace in 1997, was introduced by an established manufacturer of hot water tanks and related equipment. In addition, three or four other developmental firms are attempting to bring their products into the marketplace.

## 1.2 OBJECTIVES

The specific objectives of this Technology Profile are to:

1. Document historical activities and the present state of knowledge, degree of technological development and the level of commercialization.
2. Critique the various technologies (past and present) and provide a commentary on their technical and economic viability.
3. Assess the energy usage characteristics of existing residential hot water heating systems and identify promising applications for GWHR systems.
4. Analyze the market potential for the technology and provide a general economic assessment of residential GWHR systems.
5. Plan a workshop on residential GWHR systems.

## 1.3 SCOPE OF THE REPORT

This report has been restricted to greywater heat recovery systems which are intended for detached, semi-detached and small, multiple-unit residential buildings. It is not concerned with systems intended for commercial or industrial buildings. However, it should be appreciated that much of the discussion within this report may have application in these other sectors.

## 1.4 REPORT ORGANIZATION

As much as possible, this report has been organized according to the standard format used by other Technology Profiles commissioned by the Canadian Electrical Association (now the Canadian Electricity Association) and its member utilities. However, some departures from this format have been necessary since both residential GWHR technology and its industry are still in their adolescent stages and do not fit within the standard format as readily as more mature technologies.

## SECTION 2

## CONVENTIONAL DOMESTIC HOT WATER HEATING

### 2.1 INTRODUCTION

This section provides an overview of conventional residential domestic hot water usage characteristics as well as descriptions of the most common types of water heating systems presently in use.

### 2.2 RESIDENTIAL HOT WATER CONSUMPTION PATTERNS

One of the most critical variables affecting the economic viability of residential GWHR systems is the amount of hot water consumed per household since this defines the opportunity for energy savings. Hot water consumption varies dramatically among households and is heavily influenced by family size, lifestyle, water heater storage capacity, fuel cost, fuel type, family income, geographic location, the number and type of fixtures, etc. Many of these factors have also changed in recent years resulting in a continuing evolution of DHW consumption patterns.

Various studies have been conducted to define typical residential DHW loads. These have used techniques ranging from sub-metering of the water heater to occupant surveys to estimate household consumption. Table 1 provides a compilation of DHW consumption research which has been collected from various sources. This data shows the energy consumption of the hot water heater and includes the effects of stand-by losses from the tank and hot water piping. In some cases, the original references in Table 1 reported their results in terms of hot water usage, rather than energy consumption, in which case the data has been converted to energy units using the assumptions shown.

Table 1 also shows the DHW usage reported in terms of hot water consumption (litres/day), calculated using a common, standardized temperature rise of 49 °C (88 °F) and assumed DHW system efficiencies of 85% for electric heating and 58% for natural gas heating. This temperature rise was calculated using an average cold water inlet temperature of 11 °C (55 °F) which is the mean inlet temperature of 8 Canadian cities, and a water heater thermostat setting of 60 °C (140 °F). This equivalent hot water consumption data is only shown for the Canadian references since inlet water temperatures were probably significantly different in the American studies, which would affect energy usage.

It should also be noted that the natural gas water heater data in Table 1 does not include the secondary energy losses created by the tank resulting from the outdoor air drawn into the house to provide combustion air for the water heater and the by-pass leakage into the draft diverter. These losses were not included because their magnitude is not well established and also because they affect the space heating load rather than the DHW load.

## Table 1
## Estimates of Residential Domestic Hot Water Energy Loads (Gross)
## (Exclusive of Combustion Air & Draft Diverter Losses For Combustion Appliances)

| Reference | Energy Source | Notes | Calculated DHW Usage Based On Standardized Temperature Rise of 49 °C (88 °F) litres/day | Reported DHW Energy Consumption (Gross) | |
|---|---|---|---|---|---|
| | | | | $kWh_e$/yr | $kWh_e$/day |
| Manitoba Hydro (Kessler, 1997) | Electric | Based on a conditional demand analysis of approx. 5,000 homeowner surveys coupled with end-use monitoring of approx. 90 water heater installations; all Manitoba data. Average house occupancy 2.7 people. | 155[1] | 3,770 | 10.3 |
| Marbek (1994) | Electric | Data obtained from Ontario Hydro and B.C. Hydro. Marbek assumed an average hot water usage of 226.2 litres/day (49.8 I.G./day) with a 45 °C (81 °F) temperature rise; average house occupancy 2.9 people. | 236[1] | 5,752 | 15.8 |
| Stevenson (1983) | Electric, natural gas & oil | Data was obtained from detailed occupant surveys of over 600 single-family homes across Canada. Stevenson reported results in terms of DHW consumption. Energy estimates shown here are based on our assumed temperature rise of 49 °C (88 °F) and a system efficiency of 0.85 (i.e. electric DHW heating). Average house occupancy unknown. | 159[1] | 3,880 | 10.6 |
| Perlman and Mills (1985a) | Solar-assisted and heat pump | Based on monitoring of 58 houses for 1 to 2 years, all in Ontario. The non-conventional hot water heating systems were judged as not having had an effect on DHW consumption. Perlman and Mills reported their results in terms of DHW consumption. Energy estimates shown here are based on our assumed temperature rise of 49 °C (88 °F) and a system efficiency of 0.85 (i.e. electric DHW heating). Average house occupancy 3.9 people. | 236[1] | 5,748 | 15.7 |

| Reference | Energy Source | Notes | Calculated DHW Usage Based On Standardized Temperature Rise of 49 °C (88 °F) litres/day | Reported DHW Energy Consumption (Gross) | |
|---|---|---|---|---|---|
| | | | | $kWh_e$/yr | $kWh_e$/day |
| CGRI (1994) | Natural gas | Information collected from various Canadian gas utilities. CGRI based their results on an average hot water usage of 243.2 litres/day (53.5 I.G./day), a 50.0 °C (90 °F) temperature rise and an Energy Factor of 0.56. Average house occupancy unknown. | 258[2] | 9,195<br>(approx.[3]) | 25.2<br>(approx.[3]) |
| Hirst et al | Unknown | Based on 142 Oregon (Hood River County) homes monitored in 1984/85, non-energy efficient water heating systems. Reported in Bancroft et al (1991); results are assumed to describe the gross energy usage. Average house occupancy unknown. | | 5,040 | 13.8 |
| EPRI | Electric | Based on monitoring of 86 homes in 10 U.S. utility service areas in 1979, non-energy efficient water heating systems. Reported in Bancroft et al (1991); results are assumed to describe the gross energy usage. Average house occupancy unknown. | | 5,604 | 15.4 |

Notes:

1. Electric DHW system efficiency assumed to equal 85%.
2. Natural gas DHW system efficiency assumed to equal 58%.
3. Values shown should be treated as estimates only, the raw data which was supplied by the utilities was not based on extensive monitoring.

From Manitoba Hydro's perspective, the most relevant DHW consumption data are those developed from its own research on customer behaviour patterns. As shown in Table 1, Manitoba Hydro has estimated that the gross energy consumption for hot water heating among its customers who use electric tanks is 3,770 kilowatt-hours per year (kWh/yr) per house, or 10.3 kWh/day. This figure is based on a conditional demand analysis of approximately 5,000 customer surveys (Kessler, 1997). This method uses customer-reported data on the house, appliances, family size, lifestyle, etc., coupled with billing data, which is subjected to a detailed multiple regression analysis to produce estimates of energy usage for all the major electrical loads. The regression algorithms are derived from end-use monitoring of appliances in a sample of houses which is carried out by Manitoba Hydro on a regular basis. In the case of the DHW load, the data derived from the conditional demand analysis was compared to data from actual end-use monitoring performed on approximately 90 houses over a 2 year period. After the appropriate corrections were made for differences in family size between the 90 house sample and the 5,000 customer survey, the metered energy usage was found to be very similar to that derived from the conditional demand analysis (Godin, 1997). As a result, the utility places a high level of confidence in its estimates of DHW energy use.

What is particularly interesting about the data in Table 1 is the wide variation in reported consumption. For example, Manitoba Hydro's estimated DHW load is much smaller than that reported by most others, even those who surveyed houses with electric tanks. This may have occurred because the average family size reported by Manitoba Hydro (2.7 people) is smaller than the family size reported in the other studies. Only Stevenson's results also show a relatively low consumption. However, his data was generated using subjective determinations of water usage reported by homeowners, as opposed to objective monitoring of hot water systems by independent means. In general, the number of occupants appears to be the single most significant variable affecting DHW usage. Table 2 shows the impact of family size upon the gross DHW energy consumption using data provided by Manitoba Hydro, which is derived from the conditional demand analysis described above.

**Table 2**
**Impact of Family Size on DHW Energy Consumption (Manitoba Hydro Data)**

| Family Size | DHW Energy Consumption (Gross) (kWh/yr) |
|---|---|
| 1 person | 1,885 |
| 2 people | 3,091 |
| 2.7 people (average size) | 3,770 |
| 3 people | 4,072 |
| 4 people | 5,014 |
| 5 people | 5,844 |

## 2.3 DHW END-USES AND LOAD TYPES

It was previously noted that one of the critical factors affecting the economic viability of GWHR systems is the size of the DHW load. Another factor which is almost as important is the usage characteristics of the load. Residential hot water loads can be classified as either batch or simultaneous flow end-uses. Batch loads are those in which the flow of greywater and potable water do not occur at the same time, such as for a bath. Since the flows do not occur simultaneously, there is no direct opportunity for heat recovery. Therefore, some GWHR systems use thermal storage to hold the greywater until its recoverable energy can be removed. While thermal storage improves system performance, it adds to the overall system cost and complexity.

In contrast, simultaneous flow loads are those which occur when the greywater and potable water flows occur at the same time and with a relatively constant ratio between the two flow rates. Of the various end-uses in a house, only showers are normally classified as a pure simultaneous flow load although some washing can also be treated as such. All other end-uses are generally batch loads. Thermal storage is not needed to recovery heat from a simultaneous flow, although it may still improve performance. It is worth noting that in commercial and industrial applications, most heat recovery applications are designed to operate only under simultaneous flow conditions.

From a comfort perspective, it is also important to distinguish between these two types of loads since most comfort problems occur under simultaneous flow conditions (e.g. showering) rather than during batch loads when running out of hot water creates more of an inconvenience than a comfort problem (e.g. running out of hot water when doing the laundry).

To properly evaluate GWHR system performance, it is therefore necessary to consider the distribution between batch and simultaneous flow loads in typical households. Although the knowledge base was found to be somewhat sketchy, and somewhat dated, five sources of information on this topic were identified.

Stevenson, as part of his 1983 study into residential hot water use patterns in single-family dwellings conducted for the Canadian Electrical Association, estimated the end-use distribution of hot water in 621 houses (CEA, 1983), as shown in Table 3. However, it seems probable that changes in usage patterns have occurred since the survey was completed. For example, water conservation measures (resulting either through improvements in technology or as the result of lifestyle changes) are more common today than in 1983. Although Stevenson noted that most of his surveyed houses used DHW conservation measures (such as cold water clothes washing and rinsing), these practices are probably used to a greater extent today. Conversely, new hot water-consuming products, such as whirlpool bathtubs, have become more common - which could increase DHW usage. Nonetheless, using the data in Table 3, 41% of Stevenson's DHW load can be classified as a pure simultaneous flow. If it is assumed that a fraction of the manual dishwashing load (say one-quarter) can also be described as a simultaneous flow, then this figure increases to about 43%.

**Table 3**
**Residential Hot Water End-Uses (Stevenson)**

| End-Use | Percent | Type |
|---|---|---|
| Baths | 16.5 | Batch flow |
| Showers | 40.7 | Simultaneous flow |
| Washing machines | 24.2 | Batch flow |
| Automatic dishwashers | 9.7 | Batch flow |
| Manual dishwashing | 8.8 | Batch and simultaneous flow |
| Total | 100.0 | |

Other sources of information on end-use characteristics were also identified. In their 1988 Electric Water Heating Manual, the Canadian Electric Association presented a similar breakdown to that in Table 3 but with somewhat different data, and with ranges of values, rather than specific numbers, for some end-uses. Using the CEA data, the percentage of the DHW load which can be classified as simultaneous flows was found to be about 30% (this includes one-quarter of the manual dishwashing load).

Bancroft et al (1991) give three additional estimates of hot water end-uses drawn from studies by the California Dept. of Water Resources, Meier and Usibelli, and Geller. Unfortunately, their results combine the hot water usage reported for showers and baths. However, using data from Stevenson and the CEA, the ratio of DHW consumption for showers and baths was estimated to be 2:1, and the batch/simultaneous flow distribution for these other references were then calculated.

Based on the reported data from these three additional references, plus the Stevenson and CEA data, and making the assumptions described above, the breakdown of the DHW load into batch and simultaneous flow loads was calculated, as shown in Table 4. Using the average results from these five studies, it was concluded that about 65% of the residential DHW load can be characterized as a batch flow and about 35% as a simultaneous flow. However, it should be recognized that the information sources are somewhat dated and may not reflect current practices with respect to hot water conservation practices or the more widespread use of hot water-intensive appliances. It is also unclear what impact these changes might have on overall DHW usage.

**Table 4**
**Estimated DHW Usage Characteristics**

| Original Data Source | Batch Flows | Simultaneous Flows |
|---|---|---|
| Stevenson (Montreal Engineering) | 57% | 43% |
| CEA Electric Water Heating Manual | 70% | 30% |
| California Dept. of Water Resources | 62% | 38% |
| Meier and Usibelli | 70% | 30% |
| Geller | 67% | 33% |
| Average | 65% | 35% |

## 2.4 CONVENTIONAL DHW HEATING SYSTEMS

The thermal performance, economics, degree of customer satisfaction and ultimately the commercialization of residential GWHR systems will depend on the type and characteristics of the existing (or planned) conventional hot water heating systems. Approximately 95% of the residential hot water heaters in Canada use either electricity or natural gas as their energy source, so the discussion below will focus on them. Most of this information has been drawn from a technology review of residential electric storage tank water heaters conducted by Marbek Resource Consultants (1994) and from a report on residential gas-fired appliances prepared by the Canadian Gas Research Institute (CGRI, 1994).

The remaining 5% of the DHW market is supplied by oil heating and other miscellaneous sources (NRCan, 1995). On a national level, the use of oil DHW heating is quite minor, just over 3%, although it is significant in a few geographic locations such as Prince Edward Island and New Brunswick. In terms of the technology, oil DHW heating is roughly similar to that used for natural gas DHW heating in that they are both combustion based. However, the cost of oil heating is generally closer to that of electric DHW heating.

### 2.4.1 Electric Water Heating

Based on data published in 1992, 5.2 million households in Canada (53% of the total) used electric water heating. An estimated 400,000 to 500,000 residential electric water heaters are installed in Canada every year, the majority as replacement units. Electric water heating systems are most common in rural areas which do not have access to natural gas and in Quebec where electric heating is dominant.

In new installations, the most common tank size is the 175 litre type; which is referred to as a 40 imperial gallon (I.G.) tank, although it is actually 38.5 I.G. The second most common size is the 270 litre (60 I.G. nominal, 59.4 I.G. actual). Element sizes are typically 3.0, 3.8 or 4.5 kW with most tanks having an upper and lower element operated by a flip/flop switch to limit the peak demand. Average life expectancy of electric water heaters is estimated to be between 10 and 15 years, with an average life of 12 years, although this can be significantly lower in areas with poor water quality.

Marbek compiled statistics on the consumption of electrically heated hot water and concluded that the average usage is approximately 78 litres/day per person (17 I.G.), equivalent to 226 litres per day (50 I.G.) for a "typical" family, which they estimated as having 2.9 people. In their analysis, they assumed an average temperature rise of 45 °C (81 °F), a typical tank stand-by loss of 99 W (actual, as opposed to that derived from laboratory testing for standards compliance purposes) and distribution system losses of 66 W. This equates to an average energy consumption of 5,752 kWh/year or 15.8 kWh/day.

The magnitude of the stand-by losses are mainly determined by tank size and the amount of tank insulation. The standard describing the performance of electric storage tank water heaters is CAN/CSA-C191.1 which applies to water heaters ranging in size from 50 to 450 litres (11 I.G. to 99 I.G.) (CSA, 1990). It defines the maximum permitted stand-by losses, measured in Watts, as a function of tank size. Another relevant standard is CSA-C745 which describes how stand-by losses are converted into the Energy Factor (EF) rating system (discussed below), and is consistent with the rating system used for natural gas water heaters (CSA, 1995).

The average costs of electric water heaters, exclusive of installation charges, are summarized in Table 5. This data was generated using only Ontario results; further, wide variations were reported in the price data for other geographic regions due to differing freight costs. First cost tends to be a very important factor in consumer purchasing decisions and Marbek reported that, according to tank manufacturers, purchasers only consider the benefits of higher efficiency models in about 5% of sales.

From a safety perspective, electric tanks have the advantage that they are not susceptible to combustion spillage and backdrafting - a potential problem with some types of natural gas water heaters. However, this is not a major issue in the minds of most homeowners. From a consumer perspective, electric water tanks have two potential disadvantages - higher operating costs (relative to natural gas tanks), and a slower recovery rate. The recovery rate is the rate at which the tank can produce hot water and is largely determined by the energy input to the tank. In a typical residential natural gas tank, the energy input rate is two to three times that provided by a comparable electric tank.

**Table 5**
**Retail Prices of Electric Water Heaters (1994 Data)**

| Water Heater | Average Retail Price (approx.) |
|---|---|
| 175 Litre (40 I.G.) Water Heaters | |
| 115 W stand-by loss | $195 |
| 96 W stand-by loss | $195 |
| 85 W stand-by loss | $215 |
| 65 W stand-by loss | $325 |
| 270 Litre (60 I.G.) Water Heaters | |
| 130 W stand-by loss | $260 |
| 115 W stand-by loss | $260 |
| 100 W stand-by loss | $295 |
| 80 W stand-by loss | $380 |

### 2.4.2 Natural Gas Hot Water Heating

Natural gas water heating is mainly confined to urban areas and some smaller towns connected to the gas pipeline grid. It is most prevalent in western Canada, Ontario and to a limited degree, Quebec. In Canada, water heating accounts for 26% of the total residential natural gas consumption, with almost all of the balance being used for space heating. As of 1992, there were 4.2 million natural gas water heaters installed in Canadian households, representing 42% of all homes. An estimated $700 million is spent on natural gas every year for residential water heating, or $167 per connected house.

The Canadian Gas Research Institute conducted a series of consultations with various gas utilities across the country and concluded that the average consumption of domestic hot water was 243 litres/day (54 I.G./day) with an average temperature rise of 50 °C (90 °F). In their analysis, an average Energy Factor of 0.56 was assumed, with an average calorific value for natural gas of 37,654 kJ/m$^3$ (1,010 Btu/ft$^3$). The Energy Factor describes the thermal performance of a water heater and is defined as the amount of energy transferred to the hot water divided by the amount of energy input to the tank, when tested under standardized laboratory conditions. Thus, it includes the effects of stand-by losses, flue losses and pilot losses (i.e. that portion of the pilot light energy which does not provide heat to the water). However in the case of combustion-fired tanks, the Energy Factor does not account for the additional space heating load created by the water heater as a result of the extra outdoor air drawn into the house for combustion purposes or for by-pass leakage into the draft diverter.

The CGRI data translates into an average energy consumption of 9,198 kilowatt-hours equivalent per year (kWh$_e$/year) or 25.2 kWh$_e$/day. If an EF value less than 0.56 were used (to account for the additional space heating load created by the gas water heater), then the effective energy consumption would increase. However, the data supplied by the gas utilities to the CGRI was based on limited monitoring of actual installations and should therefore be treated with caution (S. Krsikapa, 1997).

Natural gas storage type water heaters are generally manufactured with their capacities rated in U.S. gallons. The most common sizes are the 114, 151, 189 and 227 litre models (30, 40, 50 and 60 U.S. gallons respectively). The most common size in Canadian homes is probably the 151 litre (40 U.S. gallon) size. Gas inputs range from about 10 kW$_e$ (34,000 Btu/hr) up to 22 kW$_e$ (75,000 Btu/hr). For 151 litre models, the typical input is 11.1 kW$_e$ (38,000 Btu/hr). Gas-fired storage type water heaters with inputs of less than 22 kW$_e$ (75,000 Btu/hr) are certified in accordance with CAN1-4.1-M85 (CGA, 1985). This standard was modified in 1992 to include a minimum efficiency requirement which is determined using CGA P.3-1991 (CGA, 1991). Water heaters covered by CGA P.3-1991 are required to have a minimum Energy Factor which is calculated as:

$$0.62 - (0.0005 \times \text{rated storage capacity in litres}) \qquad (1)$$

For a 151 litre tank this translates into an EF of 0.54.

Table 6 presents a summary of typical natural gas storage tank costs and type-average Energy Factors for different tank types, in various locations across the country. However, for each tank type there is considerable variation in EF values. For example, among conventional, naturally aspirated centre flue designs, the Energy Factors ranged from 0.48 to 0.59. Similarly, power-vented, sealed combustion tanks ranged from 0.63 to 0.86.

**Table 6**
**Natural Gas Water Heater Costs (1993 $)**

| Type of Water Heater | Energy Factor (avg.) | Installed Water Heater Costs ($) | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | Montreal | Toronto | Winnipeg | Regina | Calgary | Vancouver | National Average |
| Naturally Aspirated | 0.55 | $527 | $472 | $430 | $472 | $424 | $502 | $471 |
| Power-Vented | 0.55 | $1,090 | $1,068 | $1,125 | $1,085 | $1,083 | $1,284 | $1,123 |
| Direct-Vent | 0.60 | n/a | n/a | n/a | $1,128 | n/a | $1,070 | $1,099 |
| Power-Vented, Sealed Combustion | 0.75 | $1,835 | $1,765 | $1,835 | $1,815 | $1,785 | $1,885 | $1,820 |

Naturally aspirated tanks are by far the most prevalent type and dominate even in new construction. The one exception is in energy efficient houses such as those built to the R-2000 Standard which banned naturally aspirated devices several years ago for safety reasons. This type of tank has a very low first cost, is quite reliable, but suffers from a low operating efficiency and is susceptible to combustion spillage and backdrafting. Since naturally aspirated furnaces are no longer sold in Canada, the conventional gas tank is often the only spillage-susceptible appliance in a new house. Venting is normally through a double-wall B-vent.

Forced combustion or power-vented water heaters use a blower to mechanically exhaust the products of combustion outdoors, either through a B-vent or a sidewall vent. Ignition is provided by either a standing pilot or electronic ignition. Despite the presence of a blower, some of these units can still be vulnerable to combustion spillage. If the tank uses a draft diverter, then spillage is possible particularly during the off-cycle if a standing pilot is used. Combustion spillage can also occur through the B-vent since its construction is not airtight.

The third type of water heater, the direct-vent, draws combustion air directly from the outdoors through the outer portion of a concentric inlet/outlet duct arrangement where it is preheated by the hot flue gases in the inner duct. This type is resistant to combustion spillage.

The fourth type of water heater is the power-vented, sealed combustion type which draws outdoor air directly into the heater using a small blower which also vents the products of combustion outdoors. Power-vented units are usually condensing-type devices which operate with much higher EF values relative to other types of gas water heaters. Power-vented, sealed combustion water heaters are resistant to combustion spillage since they are totally separated from indoor conditions (i.e. from indoor pressures).

A rather surprising observation from Table 6 is that power-vented and direct-vent heaters show only a modest improvement in their Energy Factors relative to conventional tanks, despite the significant price premium. Not reflected in these numbers are the space heating savings which the more efficient tanks can provide if they eliminate the draft diverter. Power-vented, sealed combustion tanks provide significant improvements in the EF relative to conventional tanks but at a significant price premium - in excess of $1,300 (1993 dollars). For this reason, these tanks are often installed to provide both the hot water and space heating loads (using duct-mounted heating coils).

The estimated life of conventional tanks, using American data, was reported to range from 2 to 20 years with an average of 11 years, approximately the same as with electric tanks.

# SECTION 3

# TECHNOLOGY ANALYSIS

## 3.1 PRINCIPLE OF OPERATION

A house's wastewater stream consists of blackwater (from toilets and possibly garborators) and greywater (the remainder of the wastewater). Normally, these two streams are plumbed together in the house's drain system. Unfortunately, the solid matter in blackwater can create fouling and other problems for heat recovery devices.

Residential GWHR systems generally consist of a heat exchanger, storage tank (usually but not always) and the associated plumbing. The design of the heat exchanger can range from fairly simple to complicated, such as those in which it is integrated with the storage tank. In most designs, the house's plumbing system has to be modified so that the greywater flows which contain solids, grease and other potential contaminants are directed to by-pass the heat exchanger. The basic principle of operation of a residential greywater heat recovery systems is fairly simple. In-coming potable water from the city mains or well passes through one side of the heat exchanger while the greywater passes through the other, preheating the incoming water. After leaving the heat exchanger the potable water is plumbed to the conventional water heater, or directly to the house's hot water fixtures, or to both. Typical schematics of some commercially available systems are shown in Section 4.

Greywater temperatures range from slightly above the temperature of the mains inlet water up to perhaps 40 °C or 50 °C (104 °F or 122 °F), depending on the lifestyle of the occupants and the type of appliances in the house. From a thermodynamic perspective these are relatively low temperatures which means that recovering heat is both difficult and expensive since the surface area of the GWHR heat exchanger has to be large or must incorporate some other means to facilitate heat transfer.

Another problem is that hot water usage and greywater flows are generally very sporadic, whereas, continuous flows of the two fluid streams are desirable for optimum heat recovery. This problem is compounded by the fact that several of the main end-uses of hot water, specifically bathtubs, washing machines and dishwashers, are batch flow devices (see Tables 3 and 4) which draw hot water and discharge greywater in segmented, non-coincident lumps rather than on a continuous basis. These flows are often out of phase with each other. For example, dishwashers (which are batch flow devices) usually have a connection to only the hot water line (although some new, energy efficient models have connections to both the hot and cold water lines). Water is introduced into the cleaning chamber and circulated over the dishes and then discharged to the drain at the end of the cleaning cycle. The greywater and potable water flows never occur simultaneously. To overcome these problems, most residential GWHR systems incorporate thermal storage, holding the greywater long enough for a significant portion of the energy to be recovered. Storage tanks are generally designed to facilitate temperature stratification thereby improving performance. Some tank designs attempt to create a thermal diode effect whereby excess energy is not lost from the storage tank if greywater flows into the storage tank at a lower temperature than the potable water already present. Overall, thermal storage increases the amount of heat which can be recovered by a GWHR system, but can add significantly to overall system cost and complexity.

The energy flux of a greywater stream, i.e. the rate at which energy in the form of heat is flowing to the drain, is surprisingly high. For example, a conventional, non-energy efficient showerhead delivering 20 litres/min (4.4 I.G.•min) of mixed water at 43 °C (109 °F) will have an energy flux of 47 kW (161,000 Btu/hr), assuming an inlet water temperature of 9 °C (48 °F). In other words, when the shower is operating, it is consuming energy at the rate of 47 kW. With a low-flow showerhead, delivering (say) 12 litres/min (2.6 I.G.•min), the comparable figure is 28 kW. Obviously to recover a significant fraction of this energy requires a very efficient heat recovery device. To illustrate, compare a shower's average energy flux to that of a ventilation air stream which is introduced into a house at a flow rate of 55 litres/sec (117 $ft^3$/min) with an indoor temperature of 22 °C (72 °F) and an outdoor temperature of -33 °C (-27.4 °F). Under these conditions, the energy flux of the air stream is less than 4 kW. A Heat Recovery Ventilator (HRV) can be easily installed to preheat the air using energy from the exhaust air. However, to reclaim an equivalent percentage of the energy flux from the shower as the HRV would recover from the exhaust air stream, a GWHR system would have to recover heat at about six times the rate as the HRV. Given the cost, physical size and complexity of HRVs, the challenges faced by GWHR system designers becomes clear.

## 3.2 TYPES OF GWHR SYSTEMS

Residential GWHR systems can be broadly classified into four distinct types based on their principle of operation and the greywater loads to which they are connected. The most common type uses a combined storage tank/heat exchanger to store the greywater and preheat the potable water using thermal conduction and convection between the two fluids. Segregated plumbing, or some type of separator, is used to reduce the amount of solid matter and other contaminants entering the tank. This type of system is fairly conventional, well understood and capable of operating at reasonably efficiencies. Regular maintenance is required to keep the storage tank and heat transfer surfaces clean.

The second type of system is similar to the first but uses a heat pump between the two streams to enhance the heat recovery process. This has the advantage of achieving higher efficiencies but with greater system cost and complexity. Segregated plumbing, or some type of separator, is still required - as is regular maintenance. Both the first and second types of systems can recover heat from batch and simultaneous flows.

The third type of GWHR system uses a heat exchanger connected directly into the main wastewater line of the house (i.e. carrying greywater and blackwater). Thermal storage is generally avoided because most wastewater flows are cold and would strip heat from the storage tank. Only heat from the simultaneous flows can be captured by this type of system. Since there is no storage these systems operate at a lower overall efficiency. However system costs are also reduced. If the heat exchanger is designed as an integral component of the wastewater line, the unit can be regarded as self-cleaning and maintenance-free - which is a major advantage.

The fourth type of GWHR system can be termed a "point-of-use device" in that the heat exchanger is an integral part of a single end-use device, such as a shower. A potential problem with point-of-use type heat recovery systems is that they may require automatic or manual adjustment of the controlling valve(s) if a fixed and non-varying water delivery temperature is desired. This may require adjustment of the control valve(s) to maintain the desired temperature. A point-of-use system can only recover heat from the simultaneous flow end-use to which it is connected.

## 3.3 ENERGY AND DEMAND SAVINGS POTENTIAL

Unfortunately, there is only little information on the energy and demand savings which residential GWHR systems can produce. Proskiw (1995) conducted a detailed theoretical analysis of a conventional, combined heat exchanger/thermal storage system and concluded that the energy savings which could be achieved by an optimized system design were approximately 42% of the annual DHW load. If these savings were achieved against the average Manitoba Hydro DHW load of 3,770 kWh/yr, the savings would be 1,583 kWh/yr, worth $82/year at the current Manitoba Hydro run-off rate of 5.16 ¢/kWh.

Demand savings are mainly an issue for electric water heaters. Based on some preliminary assessments, it appears that the percentage reduction in electrical demand for an electric water heater is roughly equal to the energy savings (Eyolfson, 1998). Thus, for example, energy savings of 42% would produce energy demand savings of approximately 42%.

Additional performance data from various GWHR system manufacturers is presented in Section 5. However, additional monitoring is needed to support these estimates of energy and demand savings in real-world applications.

## 3.4 SEGREGATED PLUMBING

Most GWHR systems require segregated drain lines, i.e. the water from toilets and selected (cold water) sinks are plumbed to by-pass the greywater storage tank. This minimizes the amount of solid waste and grease which enters the tank thereby reducing the need for cleaning. Restricting the amount of cold water entering the tank also reduces thermal dilution of the greywater in the tank. While segregated plumbing reduces maintenance requirements and improves thermal performance, it increases overall costs. Depending on the layout, additional plumbing vents may also be needed. This complicates the plumbing system design in situations where there is limited space inside walls to run the extra plumbing lines. In a new house, this is a manageable problem if the plumbing requirements for the GWHR system are recognized at the design stage. However, it can create a major obstacle in existing houses and could preclude retrofitting a GWHR system into many houses since additional plumbing may have to be installed, walls opened, etc. The cost and inconvenience to the homeowners would be significant.

From a commercialization perspective, the need for segregated plumbing systems could eliminate a large part of the potential house market. Obviously, designs which do not need segregated plumbing will have a significant advantage over those which do, provided their thermal performance is not seriously impaired.

### 3.5 PHYSICAL SIZE

A typical tank-based GWHR system requires about 1 $m^2$ to 3 $m^2$ (roughly 10 $ft^2$ to 30 $ft^2$) of floor space with the largest component being the storage tank. This can create a problem if space is limited in the house. It also counters the recent trend towards smaller-sized mechanical systems. Unlike a device such as an HRV, GWHR tanks can not be easily hung from the ceiling to free up floor space. Even if the unit is installed in the basement, many consumers would consider the lost floor space to be a disadvantage. Access to the tank would have to be provided for cleaning and maintenance, potentially limiting the opportunity to use the space above the tank for storage.

### 3.6 GWHR SYSTEM LOCATION

In most applications, the GWHR system has to be installed below the level of the lowest fixture which drains into it. This can pose a problem in situations where some of the appliances are on the same floor as the GWHR system. For example, in a typical residential installation with the GWHR system located in the basement, it would be difficult to connect a basement shower into the GWHR system without additional expense for pumps and extra plumbing. Houses with crawl space or slab-on-grade foundations would have a similar disadvantage. Washing machines located on the same floor as the GWHR system would have to be able to pump their greywater up high enough for it to drain into the GWHR system. Normally, they pump the greywater about 1 m (3') into a standpipe, so this may or may not be a problem, depending on the machine. Although it should be possible to install a GWHR system on the same, or a higher, level and then pump the greywater up to the tank, this would complicate the design and introduce noise, maintenance and reliability issues. Pumps could be used but they are not seen as practical options for residential applications. The system must also be located to facilitate connection to the house's sewer line and to permit connection to a plumbing vent. In the case of a new house, this is relatively easy but would be more difficult in a retrofit application. If the GWHR system includes thermal storage, there may also have to be structural consideration given its weight. A typical tank can weigh 230 to 460 kg (500 to 1000 lbm) when full. This may be a problem on a wood frame floor system if it was not designed for such concentrated loads.

### 3.7 MAINTENANCE REQUIREMENTS

From the consumer's perspective, perhaps the greatest problem with GWHR systems is the need for occasional cleaning of the thermal storage tank, if one is included. Greywater contains grease, sludge and some solids (even assuming toilets are not plumbed to the tank) that will build-up on the inside surfaces of the tank. This process, known as fouling, can degrade the heat transfer coefficient between the greywater and potable water and can occur within a relatively short period of time. Sludge build-up is accelerated in a GWHR system since heat is being removed from the greywater (see Section 3.11).

### 3.8 POTENTIAL CONTAMINATION OF THE POTABLE WATER SUPPLY

Contamination of the potable water supply by leakage from the greywater stream is an obvious concern but one which can be easily dealt with, at least from a technical perspective. Most GWHR systems use double-wall heat exchanger/storage tanks so that there are two walls or membranes separating the potable and greywater streams. Also, since the potable water line is normally pressurized relative to the greywater line, any leakage which does occur would take place from the potable water line into the greywater, not in the opposite direction.

From a marketing perspective however, perhaps the bigger threat is the consumer's perception that contamination can occur - even if that threat is negligible. There is always the concern that consumers will think sewage is leaking into the potable water any time an unexplained odour emanates from the water supply (which does occur from time to time).

Although there appears to be little actual risk of contamination of potable water by a GWHR system, this issue could still create a cost and regulatory obstacle for manufacturers. At present, the Federal government is considering legislation intended to protect drinking water supplies. This bill, known as the "Drinking Water Materials Safety Act" would apply to components of plumbing systems which carry or come into contact with potable water (Health Canada, 1997). One of its provisions would require manufacturers of such equipment to undergo an accreditation and certification procedure so that the safety of their products could be verified. Presumably this legislation would apply to GWHR systems. Although meeting the requirements should not be difficult for a GWHR system, it would still create an additional cost for the manufacturers to endure.

### 3.9 TEMPERATURE CONTROL OF THE DOMESTIC HOT WATER

In some situations, a GWHR system may cause a slight fluctuation in the temperature of the delivered hot water. Without heat recovery, the hot water temperature at faucets, showerheads and other end-uses, is usually initially lower than the temperature of the water in the DHW tank (due to heat losses from the plumbing). As the hot water starts to flow, the cold water in the lines is replaced with hot water and a steady-state delivery temperature at the end-use is reached which is then maintained until all of the hot water in the tank is consumed. If a GWHR system is added, a further temperature dynamic is introduced since the degree of preheating by the GWHR system depends on the temperature of the water going to the drain. Although this may prove to not be a significant problem, it could require homeowners to adjust to a new "temperature behaviour" at their shower or sink.

## 3.10 POTENTIAL TECHNICAL OBSTACLES

Table 7 summarizes the obstacles discussed above which designers of residential GWHR systems will have to address. The issue of system costs is discussed in Section 6.

**Table 7**
**Potential Technical Obstacles**

1. Controlling installed system costs
2. Need for segregated plumbing
3. Physical size, lost floor space and the need to be located below the sources of greywater
4. Fouling (need for maintenance)
5. Possibility/perception of contamination
6. Temperature control of the domestic hot water at the end-use

## 3.11 PRODUCT RELIABILITY ISSUES AND OPERATIONAL CONSIDERATIONS

### 3.11.1 Storage Tank Cleaning

The rate of sludge build-up from the greywater onto a surface is related to the average temperature of the greywater; the lower the temperature, the greater the build-up. GWHR systems remove heat from the greywater which increases the amount of sludge deposition. This problem is aggravated in GWHR systems which use a combined storage tank/heat exchanger because the average water velocity over the heat transfer surfaces is very low, further promoting sludge deposition. The only types of system which do not suffer from this problem are those which have the greywater moving at relatively fast velocities. This issue was studied by the U.S. Dept. of Energy who concluded that fast-moving soapy films in a vertical, straight installation will keep the pipe free of nonorganic deposits (Energy Design Update, 1997).

Based on the limited documented experience with GWHR systems, storage tank cleaning may be required somewhere between once every few weeks to once every few months, and would take approximately 1 hour to perform, assuming manual cleaning. Historically, most GWHR systems have relied upon manual cleaning by the homeowner. The limitation of this approach is the willingness, or lack thereof, of most people to perform a task which would expose them to smells and rather disagreeable substances when the tank is opened. Odour migration to other parts of the house (when the tank is open) would also occur rapidly. Access to a floor drain may be required.

A parallel can be drawn to the level of maintenance provided by owners of residential Heat Recovery Ventilators. Modern versions of these appliances can be easily disassembled for cleaning (generally without tools) and do not present objectionable odours or sights to the homeowner. The entire task can be completed in about 10 minutes. Despite the simplicity of cleaning an HRV, the majority of homeowners seldom perform the task. This has prompted some manufacturers to add maintenance reminder lights to HRVs which automatically indicate when maintenance is required. It seems doubtful that most homeowners could be expected to regularly clean a GWHR tank.

The alternative to manual cleaning is to use an automatic system which drains the greywater and washes down the tank's inner surface. This approach was used by Pemberton in his heat pump heat recovery system (discussed in Section 4). The disadvantage of this approach is the extra cost plus the impact upon system reliability since an additional electrical/mechanical control system is required.

It is worth noting that similar experiences have been encountered with heat pump-based wastewater heat recovery systems designed for commercial and industrial applications. Although several systems have been developed and commissioned in Canada, the U.S. and Europe, they have generally not been as successful as anticipated, mainly due to maintenance problems (CEA, 1988).

### 3.11.2 Odours

To achieve acceptance in the modern consumer market, a successful GWHR system should be virtually odour-free during normal operation. If the system contains a greywater storage tank this will be of concern since odours may be produced by the greywater, even if segregated plumbing is used to divert blackwater away from the tank. Although it is relatively easy to build an airtight tank, odours will appear whenever the tank is opened for maintenance. Suggestions have been made that it may be possible to reduce the generation of odours from the greywater by controlling the chemistry of the greywater through additives. Whether or not this is possible is unclear, however it would introduce an additional cost, maintenance and (possibly) environmental burden.

### 3.11.3 Water Leaks

A residential GWHR system has to achieve the same level of reliability as any other plumbing device, i.e. water leaks can be tolerated only on a very infrequent basis if consumer acceptance is to be maintained. Nonetheless, if the system contains a storage tank, it should be located on a moisture-resistance surface and situated with easy access to a floor drain. For installations in a basement, this would not normally be a problem. If the storage tank is located on a finished floor, then it should be installed in a water-tight drain pan, of the type occasionally used underneath hot water storage heaters.

### 3.11.4 Septic Tanks

Septic tanks, which are common in rural areas, may - or may not - suffer a loss of performance if a greywater heat recovery system is installed. Septic systems only operate when their temperature is maintained above certain levels and some of this heat is supplied by the greywater. Presumably, if a significant amount of energy were removed by a GWHR system, the average temperature of the septic system would be lower and its overall biological performance could suffer. However, further research is required on this issue.

## 3.12 HEALTH AND SAFETY CONSIDERATIONS

Obviously, the major safety consideration with a residential GWHR system is potential contamination of the potable water supply by the greywater. Not only is leakage between the two sides of the system a concern, but so is the possibility that the leakage will go undetected for an extended period of time resulting in continuous contamination of the potable water supply. Therefore, most plumbing authorities require some form of double-wall heat exchanger to be used between potable and contaminated water streams. For contamination to take place, failure of both walls would have to occur. In most cases, there is the additional level of protection provided by the potable water line being pressurized relative to the greywater (other than when the pressure in the potable water line has been reduced, say for repairs). In the event of a double wall failure, the leakage would normally take place from the potable water to the greywater - not the other way around. A final level of protection can also be provided if drainage is provided between the two fluid channels. For example, in the system designed for the Manitoba Advanced House (see Section 4), the space between the potable water preheat coil and the greywater liner contained drainage holes so that leakage from either side of the system would drain onto the floor thereby alerting the homeowner to the problem.

## 3.13 REDUCTIONS IN GREENHOUSE GAS EMISSIONS

If the hot water heater uses a primary energy source which produces greenhouse gases, the addition of a GWHR system will reduce these emissions in direct proportion to the reduction in the water heater's gross energy consumption. For example, if a natural gas water heater is used, 50 tonnes of carbon dioxide ($CO_2$) are produced for every terajoule (TJ or $1 \times 10^{12}$ joules) of energy consumed at the water heater (Environment Canada, 1992). If this value is converted into more familiar units, the result is that 1 $\mathrm{kWh}_e$ of natural gas consumed produces about 0.00018 tonnes of $CO_2$. Thus, a GWHR system which saves 1000 $\mathrm{kWh}_e$ of natural gas per year would reduce the annual production of $CO_2$ by 0.18 tonnes. The reduction of greenhouse emissions for electric hot water heaters depends on whether the electricity is produced by hydraulic or thermal means. Hydraulic generation, which is how Manitoba Hydro produces virtually all of its energy, does not create greenhouse gases. In contrast, thermal stations produce significant amounts. For example, coal-generated electricity results in approximately 80 to 95 tonnes of $CO_2$ per TJ of heat produced, depending on the type of coal used, etc. When the efficiency of the generating station and the transmission losses are also considered, the production efficiency of the electricity which is delivered to the water heater is only about 35%. Therefore, every 1 $\mathrm{kWh}_e$ of electricity saved at the water heater reduces the emission of $CO_2$ by 0.00082 to 0.00097 tonnes. A GWHR system which saves 1000 $\mathrm{kWh}_e$ of thermally generated electricity per year would reduce the annual production of $CO_2$ by 0.82 to 0.97 tonnes.

## 3.14 IMPACT OF TECHNICAL IMPROVEMENTS TO THE TECHNOLOGY

### 3.14.1 The Need For Improved Testing

The research conducted for this study clearly identified testing as one of the main areas in which better information is needed, both with respect to the thermal performance of GWHR systems as well as their operational characteristics. Assessing and accurately describing the thermal characteristics is particularly important since system performance is very dependent upon the application, particularly the total DHW usage, the usage schedule and its characteristics (i.e. the distribution between batch and simultaneous flows). Improved and standardized test methods are needed to obtain reliable data on these issues.

The most significant work in this area was performed at Ontario Hydro in the mid-1980's (Perlman and Mills, 1985b). They developed a test specification for the laboratory evaluation of heat pump wastewater heat recovery systems and used it to evaluate an actual system. Their test specification dealt with both safety and performance issues and included specific tests for system components, energy recovery, recovery time, stand-by losses and a simulated-use test. This procedure would provide an excellent starting point for the development of a test method to evaluate the thermal, and other, characteristics, of GWHR systems. However, it would have to be carefully reviewed since the procedure was originally developed for a specific type of system (the Electrohome/Pemberton Heatcatcher). Also, the "simulated-use test" would have to be modified to include both non-coincident batch flows and simultaneous flows. When the procedure was originally developed, GWHR systems were envisioned to all contain thermal storage so the non-coincident nature of batch flows was not regarded as an issue. However, for systems without storage, it is critical that the test procedure accurately reflect the true flow characteristics since the amount of heat recovered can change dramatically depending on the flow regime. Unfortunately, this will not be an easy task because of the tremendous variation which exists in DHW usage among households. Although a "reasonably representative" profile can be generated, the deviation from this norm will be significant, suggesting that more than one profile may be required to properly bracket system performance.

Thermal testing may also be complicated by the large thermal mass of the GWHR storage tank (if one is included) since it can take considerable time for thermal equilibrium to be established. During the steady-state testing conducted on the GWHR system in the Manitoba Advanced House, it took over 200 hours to achieve thermal equilibrium (see Section 4). Presumably the time could be reduced by pre-conditioning the tank water to a temperature profile which better replicates typical conditions, although a procedure for defining the temperature profile would also have to be developed. Nonetheless, the time to adequately test under representative dynamic conditions a GWHR device which uses thermal storage would be significant - perhaps a month or more. Of course, for most of this period the test rig could be operating unattended so the labour costs would not be as onerous as might be expected.

The distinction should also be drawn between appliance testing and system testing. The discussion so far has focused on appliance testing, i.e. evaluating the performance of the GWHR device. When it is installed in a house and all the associated plumbing is connected, the performance of the system (i.e. appliance plus the rest of the system) will differ from that of the device itself due to heat losses/gains to the occupied space, interactions with the rest of the hot water system, etc. Likewise, the DHW system performance will differ from that of the hot water tank itself. Since these system-related factors are unique to the installation (i.e. the house) they can only be accounted for with knowledge of the house's behaviour. Energy simulation models such as HOT2000 use information on the DHW tank performance, combined with data on house temperature, water temperature, etc., to predict the performance of the DHW system. Similar models need to be developed for GWHR systems.

Historically, most greywater systems have been developed for research or demonstration purposes and have been subjected to some form of "testing", usually employing an ad-hoc protocol specific to that product. This parallels the development history of other energy-related products with dynamic operating characteristics - such as HRVs and solar collectors. The problem with product-specific testing is that the protocols tend to be loosely-defined, of variable quality and often constructed (intentionally or otherwise) to show the product in the best possible light. Results are typically reported with such statements as "the system supplied x% of the DHW load", with little elaboration of how the DHW load was defined, the temperatures or temperature schedules for the potable water and greywater, their respective flow rates, characteristics, etc. All of these are critical to GWHR system performance. Without standardized test procedures, it is difficult to make meaningful comparisons between systems or even reasonable assessments of individual systems.

Given these observations, a few recommendations can be made regarding the role of testing in the development of GWHR products and systems. During the product development phase, it would be desirable for a test facility to be available in the same physical location where the product development work is being conducted. Its main purpose would be to provide quantitative data on the thermal performance of the system using a standardized test protocol. Operational information (reliability, component performance, etc.) could also be collected using the facility although this would be a secondary function.

Simultaneously, a computer model of the system should be developed and validated against the results obtained from the test facility. The value of the model is that it would permit sensitivity analyses to be conducted to evaluate design modifications and to assess the impact of different operational conditions (flow rates, temperature regimes, etc.). During the analysis of the GWHR system in the Manitoba Advanced House, the thermal simulation model identified several design changes which could have been made that would have improved performance and reduced the cost and size of the system (Proskiw, 1995). Unfortunately, the model was not available during the development phase.

Once the development phase is completed (or at least the preliminary part of it), field testing can commence. The GWHR system should be installed in a number of occupied houses, selected for their representativeness and accessibility (an important point since regular access will be required). The purpose of the field testing would mainly be to gather qualitative information on the system and should consist largely of observations and homeowner comments. Considering the costs involved, only limited thermal testing should be attempted in these houses. Due to the dynamic nature of GWHR systems, field testing may require a relatively expensive (and somewhat sophisticated) data acquisition system to monitor thermal response. Detailed thermal evaluations should be restricted to a small number of houses rather than attempting cursory monitoring in a large number of homes (this can be re-phrased into the author's most cherished observation on experimental procedures, namely that "bad data is worse than no data"). If possible, independent testing by unbiased third parties should also be encouraged, although the details of the monitoring protocol have to be established and agreed upon in advance. Information from the field testing can then be fed back into the development loop to arrive at a final product/system design.

### 3.15 TECHNOLOGIES WHICH MAY IMPROVE RESIDENTIAL GWHR SYSTEMS

Compared to the research which has been directed to the development of new products or to improve the performance of existing products for other types of residential appliances (such as heating and ventilation systems), the investment in greywater heat recovery systems has been minuscule. Further, much of this effort has also done little to advance the technology. In many instances existing concepts previously developed by other individuals or organizations were simply re-discovered. Therefore, it is worthwhile to briefly consider other technologies which *may* have application in residential GWHR systems.

The first technology worth noting is the heat pipe. This simple device, which consists of a sealed tube containing a wick and a suitable refrigerant operating under a very low pressure, has the ability to transfer enormous amounts of heat between bodies at different temperatures without any moving parts. Heat boils the refrigerant in one end of the pipe (known as the evaporator). The gas, driven by a vapour pressure gradient, flows to the other end (the condenser) where it is converted back to a liquid state thereby releasing heat in the process. The liquid flows back to the evaporator through capillary or gravity action. The bulk of the heat transfer within the heat pipe occurs isothermally by phase change rather than by conduction. This closed-loop process continues as long as there is a temperature difference between the two ends. Heat transfer along the heat pipe is up to 1000 times faster than through an equivalent piece of copper (ASHRAE, 1996).

Another related technology is the thermosyphon process. Thermosyphon systems are similar to heat pipes except that they do not use a wick to return the refrigerant back to the evaporator but instead rely on gravity action. Thermosyphon systems also depend, at least initially, on nucleate boiling (a process in which energetic bubbles form as the liquid boils), whereas heat pipes operate using pool boiling - a process in which the fluid is vapourized from a large, liquid/vapour interface. As a result, thermosyphon systems usually require a larger temperature difference to operate. Since there is no wick and they rely upon gravity for condensate return, they can be installed so as to transfer heat in one direction only - a characteristic which could be very valuable with GWHR systems. Thermosyphon systems can be designed as either sealed tubes or as loops in which the evaporator and condenser are physically separated but connected by piping. Like heat pipes, they also have the ability to transfer enormous amounts of heat without any moving parts and with very high reliability.

Both heat pipes and thermosyphon systems have been used for many years in numerous industrial and commercial applications. They have also been used in some residential HRVs and solar collectors although their penetration into the residential marketplace has otherwise been limited. Some of the best work on the application of these devices in residential environments has been conducted at the Brace Research Institute of McGill University (see for example: Le Normand, 1982; Grey, 1982; Gungor, 1987; and Gomez, 1992) who have conducted extensive research and development in this field. Interestingly, their work was intended mainly for Third World applications where reliability, low cost and ease of manufacture are of primary concern.

## 3.16 ENERGY CONSERVATION ALTERNATIVES

A rational analysis of GWHR systems has to consider energy conservation as a competing alternative for investment dollars. It is often assumed that hot water conservation and GWHR systems are best used in combination. In fact the opposite is true. The best applications for GWHR systems are those in which large volumes of hot water are consumed thereby creating an ample source of potential energy available for heat recovery. The fixed cost of the installation will not change with a large load (until it is so large that a higher capacity system is required) while the impact on operating costs will either be zero or, for a heat pump-based system, relatively small.

Technologies intended to reduce the use of hot water include low-flow showerheads, faucet aerators, water efficient dishwashers, pipe insulation, cold water detergents for clothes washing, anti-circulation devices and point-of-use water heaters to reduce line losses. Some of these, such as pipe insulation, are relatively lifestyle independent. Others, such as low-flow showerheads and cold water clothes washing, require acceptance by the consumer. As more information becomes available on the performance of GWHR systems, their economics of operation should not only be evaluated as independent investment options but also compared against energy conservation alternatives which may be applicable to the load.

## 3.17 GREYWATER HEAT RECOVERY AND WATER RECYCLING

Water recycling is an emerging technology which may eventually see significant utilization in the residential sector. The water supply to most homes is treated to a very high level of purity even though a large portion of the water uses could be met with non-potable, less costly water. For example, greywater from washing activities can be treated and recycled for use in toilets. Depending on the design of the plumbing system, water recycling and GWHR technologies may form a natural fit. Water recycling systems use segregated plumbing to separate flows based on the type of water: clean water, greywater, blackwater, etc. This could facilitate the use of tank-based GWHR systems since they require separation of the flows to minimize the entry of solids and grease. Depending on the design of the water recycling system, some parts of the wastewater streams may be at higher temperatures because portions of the cold wastewater (as distinct from tepid wastewater) are plumbed separately. These higher temperatures would make it easier to recover heat from that wastewater stream. Since the plumbing for a water recycling system is more complex than normal, the integration of GWHR requires more careful, detailed analysis. Canada Mortgage and Housing Corp. recently released WATERSAVE, a PC-based design tool developed by the Centre for Water Resource Studies of the Technical University of Nova Scotia (CMHC). WATERSAVE was developed to analyze residential water recycling systems and model various types of innovative water systems. It also has a limited capability to analyze heat recovery on the greywater stream as one of its options.

One of the initial markets for water recycling technology may be northern applications since water can be quite expensive in some communities. This is also one of the possible niche markets for GWHR systems since these areas also have very high energy rates (see Section 6.4.4). Such locations would be prime candidates for combined water recycling/GWHR systems.

## 3.18 NON-RESIDENTIAL APPLICATIONS OF GWHR TECHNOLOGY

Although the scope of this report is limited to residential applications, it is worthwhile to note some very attractive "near-residential" applications for GWHR systems since they both could use the same types of products. As previously discussed, the best applications are those which have a large, relatively continuous requirement for hot water, preferably one which does not introduce significant amounts of grease or other contaminants into the greywater. Also, if the load is predominately a process, as opposed to a batch, flow there may be an opportunity to use a cheaper, storage-less system. From a commercialization perspective, it may be desirable to focus initially on these applications, develop the technology to a sufficiently advanced state, and then move into the residential marketplace.

Applications which nicely fit these requirements include glass-washing machines in bars and restaurants, dishwashers in restaurants (particularly those where most of the load is cups and glasses - such as donut shops), commercial laundries and kitchens, showers in public swimming pools and dormitories, as well as some manufacturing processes.

# SECTION 4

# HISTORICAL ACTIVITIES

## 4.1 HISTORICAL ACTIVITIES

This section briefly reviews the major historical developments, research activities and demonstration projects which have taken place with residential GWHR systems. Although this description is probably incomplete, it is believed to provide a reasonable overview of the major activities - particularly those which have taken place in Canada. The activities are listed in their approximate chronological order.

### 4.1.1 Saskatchewan Conservation House

The Saskatchewan Conservation House was the first major North American demonstration project of energy efficient housing and pioneered many concepts which have become common in new housing stock including airtight construction, superinsulation, mechanical ventilation with heat recovery, etc. Built in 1977, the design included a prototype single-wall, tank-in-a-tank greywater heat recovery system. Monitoring by the National Research Council indicated that the system was able to provide about 20% to 30% of the heat which would normally have been wasted in the greywater (Dumont, 1997). Interestingly, the house contained a crude HRV which helped to spur commercialization of that technology and the eventual creation of an industry, while the greywater system failed to attract any serious interest.

As an adjunct to their work on the Saskatchewan Conservation House, Dumont and Besant also carried out theoretical and laboratory studies in the late 1970s to evaluate various GWHR system configurations, particularly coil-in-tank and tank-in-tank designs. They also developed some useful equations to describe the heat transfer characteristics of these types of designs.

### 4.1.2. Pemberton Greywater Heat Recovery System

In the 1980s, the Canadian Electrical Association sponsored a series of research projects by Eric Pemberton of Electrohome Ltd. to develop a greywater system which used a 1.2 kW heat pump to enhance the heat recovery process, (Pemberton, 1977; 1980; 1983). The system, ultimately labelled the "Heatcatcher", used a 455 litre (100 I.G.) wastewater tank which accepted all the greywater flow generated in the house except that from the toilets. Underneath the tank was the water-to-water heat pump which extracted heat from the greywater and supplied it, along with the compressor heat, to a modified 273 litre (60 gal.) electric hot water heater with a 3 kW element. The water heater was divided into an upper, resistance heater section and a lower, preheat volume (although there was no physical separation between the two). Sludge control was identified as a major potential problem, so an automatic drain-down and rinse system was developed to remove sludge and prevent the build-up of deposits. The system was timer-controlled and activated every 2 weeks. Operation of the first prototype for extended periods without cleaning had shown that sludge build-up occurred on the tank bottom and at the top. The sediment on the bottom was easily flushed away with a hose while the top layer was reported as much thicker and had to be scrapped off once it had been allowed to accumulate. Between these two layers, the water was described as being dirty and soapy but relatively free of extraneous material.

One of the other technical issues investigated during the development of this product was the impact which widespread use of residential GWHR systems would have on municipal sewage treatment plant efficiency. Pemberton expressed the concern that large numbers of greywater heat recovery systems could significantly reduce the average temperature of the wastewater as it arrives at the sewage treatment plant, thereby retarding some of the temperature-sensitive phases in the treatment process. However, the analysis found that net impact on municipal treatment plant efficiency would be minor and that effluent standards could be easily maintained at the plant.

Perhaps what was most interesting about this system is that it was subjected to a consistent, systematic period of development - fairly unique for a residential GWHR system. The first proof-of-concept model supplied only 28% of the DHW load which was subsequently improved to 44% for the second prototype and eventually to between 60% and 70% in the third and final version. Significant improvements in its design and performance were realized through continuous optimization efforts. The success of this development process is worth noting for those wishing to commercialize residential GWHR technology.

Analysis of the final version indicated that it would supply approximately 60% to 70% of an assumed annual DHW load of 6,200 kWh/yr, or about 3,700 kWh/yr. The retail price for the system (in early-1980s dollars) was estimated at between $650 and $1025 (which includes installation costs), depending on the size of the greywater holding tank. At the time, it was estimated that the simple payback period for the system would be about five years. There was also a beneficial load-levelling effect produced by the device (although it does not appear that this was quantified).

Electrohome also conducted a marketing study for the system since their goal was commercialization. They concluded that there was only a minimal market in North America, but thought that a combination of cost reductions and electric utility rate escalations could improve the prospects. The marketing study placed great emphasis on payback periods as being the deciding criterion from the consumer's perspective. As discussed in Section 6, experiences over the last 15 years with the commercialization of energy conservation technologies suggests that the non-economic benefits (provided by the technology) should be emphasized instead. As a post-script, an attempt was also made by Vern Martin (a colleague of Pemberton) to commercialize the technology, but it was not successful.

The Pemberton experience also served as the impetus for the development of the greywater system testing protocol by Perlman and Mills.

### 4.1.3 Price Greywater Heat Recovery System (Alberta)

C.R. Price of Dirk and Price Engineering Ltd. conducted a research project for the Alberta Dept. of Housing in 1986 to design, construct and monitor a residential GWHR system (Price, 1984). The eventual design was fairly conventional, except that a single-wall heat exchanger, rather than a double-wall, was used. Maintenance requirements consisted of an annual water rinse. The system was operated for more than a year and monitoring indicated that it supplied 27% of the house's DHW load. Payback periods were claimed to range from 2 to 6 years, depending on whether electricity or natural gas was being displaced. No further activities with the system are known to have taken place.

### 4.1.4 Brampton Advanced House

The Brampton Advanced House was constructed in 1989 to demonstrate a number of innovative energy conservation technologies and also served as a catalyst for the Advanced Houses Program (Enermodal Engineering Ltd., 1992). It used an integrated mechanical system with a central heat pump and a large phase-change storage tank containing brine. A greywater heat recovery system was also incorporated into the design (Allen, 1997). The greywater heat exchanger consisted of a 5 cm (2") copper line, containing the greywater, soldered along its length to a 1.3 cm (1/2") copper tube containing the brine. The unit was 5 m (16') in length and was hung from the basement ceiling in a horizontal configuration. This may have made it vulnerable to sludge build-up and necessitated regular maintenance. The GWHR system used the existing DHW tank as its storage tank. Since the brine was cooled by the main heat pump, very advantageous temperature differentials could be achieved between the two fluid streams. At times, the discharge temperatures of the greywater were reported as being lower than the in-coming potable water. Limited bench testing indicated that the system could supply about 5,000 kWh/yr, which consisted of 3,500 kWh/yr of recovered heat and 1,500 kWh/yr of compressor heat. In-depth monitoring was not performed nor was cost data produced.

The Brampton GWHR system was quite unique in that it was designed for a house with a sophisticated whole-house heat recovery system, it would be difficult to use in a home with a more conventional mechanical system. Still, the heat exchanger, while quite simple, was an interesting and probably effective design. In fact, a logical evolution of this design can be recognized in the form of the Vaughn GFX system (discussed in Section 5) - except that the heat exchanger is positioned vertically, enlarged to eliminate the sludge build-up problem and modified to increase the contact area between the two fluid streams.

### 4.1.5 Manitoba Advanced House Greywater System

A prototype GWHR system was designed and installed in 1992 in the Manitoba Advanced House in Winnipeg (Proskiw, 1995). The design was relatively conventional and used a high density polyethylene storage tank with a 20 mil flexible polyethylene liner. The potable water preheat coil consisted of 34 m (112 ft) of 32 mm (1.25") copper tubing positioned between the liner and the exterior walls of the storage tank. The coil was plumbed directly to the inlet side of the hot water tank. The sides and top of the tank were insulated with 25 mm (1") of rigid glass fibre insulation. Total weight of the storage tank was approximately 386 kg (850 lbm), loaded. Segregated plumbing was used to keep cold and blackwater flows out of the storage tank.

The monitoring data was used to develop a finite-difference thermal simulation model to predict the performance of GWHR systems which have the same general thermal and thermodynamic configurations. Given the dynamic conditions under which GWHR systems operate, this was a particularly useful development since it allowed many different design configurations and operational conditions to be efficiently explored. The highly dynamic nature of the load required very fine time increments - ultimately a time step of 1 minute was used in the model.

The simulation model was also used to predict the technically achievable savings which could be produced by this type of GWHR system. Using typical operating and environmental conditionals, it was found that the practical performance limit for this type of system was about 42% of a typical family's DHW load. This optimum design was found to be fairly similar to the system actually used in the Manitoba Advanced House except more tank insulation would have been employed, the mass of greywater in the tank would have been reduced, the mass of potable water in the preheat coil would have been increased and a larger thermal conductance between the potable water and the greywater would have been needed.

The impact of a number of design and operational variables was also studied using the model. These were categorized as having either a minor or a major impact on overall system performance. The minor variables were found to be: tank insulation levels, mass of greywater in the storage tank and the air temperature of the room in which the tank was located (which affects skin losses). The major variables were: the mass of potable water in the preheat coil, potable water inlet temperature, greywater temperature, DHW set point temperature, the thermal conductance between the potable water and greywater, the greywater and potable water flow rates (acting together) and the greywater flow rate (acting in isolation).

The project also provided some insight into the problems of monitoring residential GWHR systems. During the development of the model, it was recognized that an empirically-derived numerical value was needed for the overall thermal conductance between the greywater and potable water. An experiment was developed in which the system was operated until it achieved steady-state conditions both with respect to temperatures and flow rates. The house was unoccupied at the time. While the test did not replicate the actual, dynamic operation of a real installation, it did permit the thermal conductance to be empirically determined. Due to the large thermal mass of the storage tank, it took approximately 200 hours of continuous operation to establish thermal equilibrium. From an experimental perspective, it was a relatively straightforward procedure. However, had a dynamic test been attempted, in which flow rates and temperatures varied according to some schedule, the difficulty, time and expense would have increased significantly.

Perhaps most importantly, the analysis concluded that the success of any GWHR system depends as much, or more, on proper selection of the application as it does on the design of the system. Ideal applications were defined as those which have large DHW loads and which can not (or will not) take advantage of conservation measures intended to reduce DHW consumption.

### 4.1.6 Alberta Sustainable House

A custom-built GWHR system was designed and installed in the Alberta Sustainable House (ASH) in 1995 (Ostrowski, 1997). The unit used a relatively conventional storage/preheat design with a plastic bag liner inside a copper potable water coil. One novel feature of the system was that the clothes dryer exhaust could be ducted over the preheat coil thereby recovering some of the waste heat in the dryer exhaust. No monitoring results have been reported to date.

### 4.1.7 European Activities

Information on European GWHR activities has been relatively sparse although some demonstration and research projects are known to have taken place as well as some attempts at commercialization. For example, the Wädenswil Zero Heating Energy Buildings Project in Switzerland - a five house demonstration project completed in 1989 - used a GWHR system with 200 litre (44 I.G.) potable water and greywater tanks separated by a metal and polyethylene plate (CADDET, 1995). It reportedly captured about 50% of the heat in the greywater. The installed cost was reported as $5,600 (U.S. dollars) while the savings were only 660 kWh/year. Other activities, particularly in Scandinavia have been reported but few details have been identified.

## SECTION 5

## CURRENT ACTIVITIES

### 5.1 CURRENT ACTIVITIES BY CANADIAN UTILITIES AND PROVINCIAL GOVERNMENT DEPARTMENTS

An informal telephone survey was conducted to determine if any Canadian utilities or provincial government departments were conducting, or planning to conduct, projects relating to residential greywater heat recovery. Representatives from B.C. Hydro, Ontario Hydro, Nova Scotia Power, Hydro Quebec, Newfoundland Dept. of Environment and Labour, and the Ontario Ministry of Environment and Energy were contacted. The responses were largely negative. Some historical activities were noted as well as one or two small monitoring projects but otherwise there was no significant activity reported. Most utilities are currently restricting their DHW activities to the promotion of energy efficient water heaters.

### 5.2 AN OVERVIEW OF THE PRODUCT DEVELOPMENT PROCESS

The development and commercialization of new products can be divided into four stages ranging from initial conception to full market penetration. These are briefly described below to provide a framework for discussing current commercial GWHR developments.

1. Basic Research
   This stage identifies the basic operating fundamentals, processes, principles, materials, etc. which the product will use along with some demonstration of their functionality as a group; concerns with costs and efficiency are secondary.

2. Applied Research
   The basic research is applied to a specific application to demonstrate and assess its capability to fulfil a need and determine its relative performance; some consideration is given to potential production costs.

3. Product Development
   The product is developed with due consideration for production costs, design optimization, maintenance considerations, marketability, safety concerns, etc; various design alternatives may still be considered.

4. Commercialization
   Product development is complete and efforts are now directed at setting up production, marketing the product, developing a distribution network and generally retrieving the original investment made in the preceding phases.

## 5.3 COMMERCIAL ACTIVITIES

Five firms were identified who are presently marketing, or attempting to bring to market, residential GWHR systems. Each product is discussed below and a summary of their key characteristics, strengths and weaknesses is given in Table 8 at the end of this section.

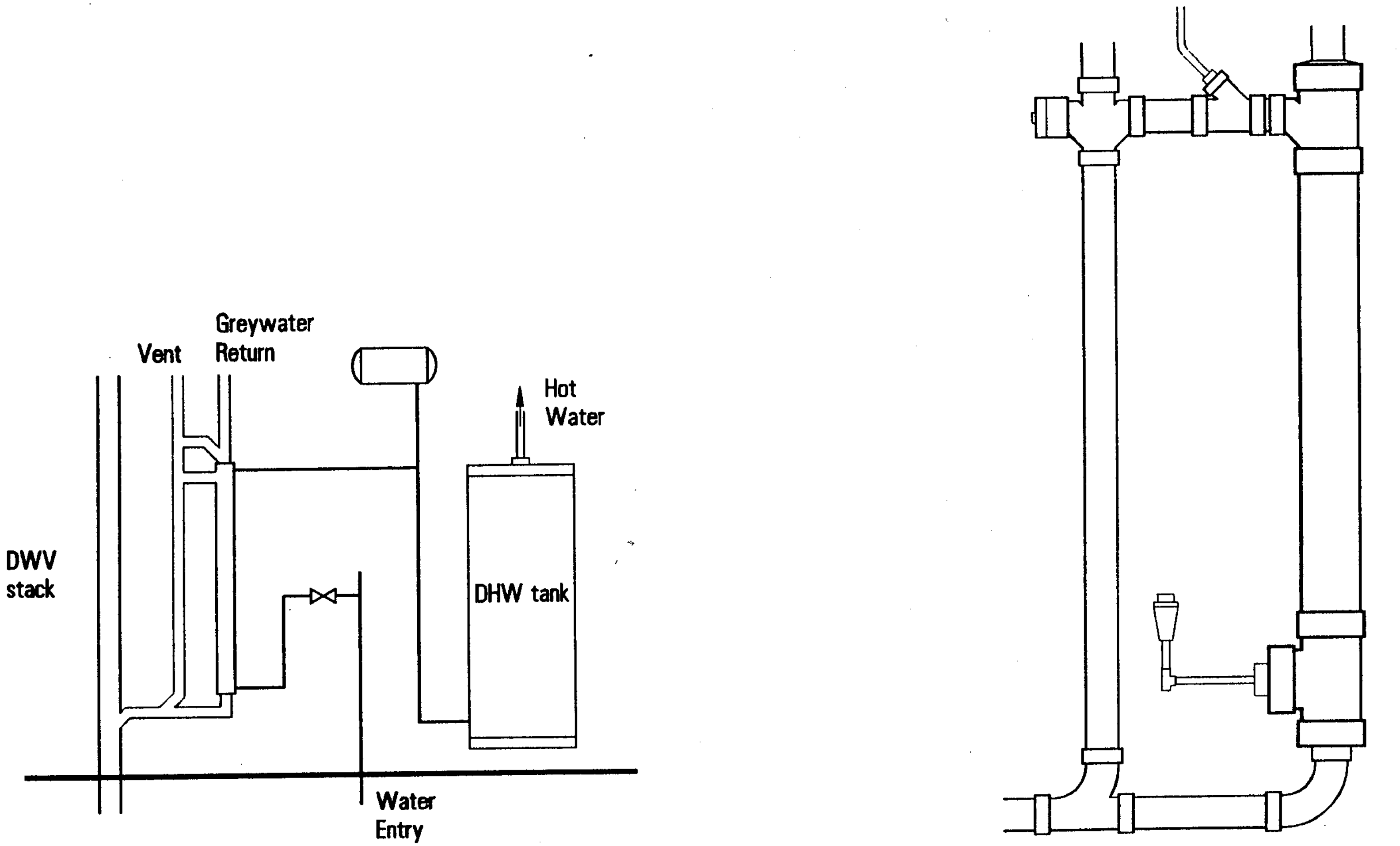
### 5.3.1 Aqua-Thermal

Aqua-Thermal, based in St. Jean-sur-Richelieu, Quebec, is in the process of bringing a GWHR system to market. The developer, Rejean Bedard, has been working on GWHR systems for several years and has had a unit installed in his home for the last year and a half. As shown in Fig. 1, greywater (exclusive of that from the toilets) flows through a vertical plastic ABS pipe around which there is a concentric chamber in which circulates the potable water flow. Presumably the system takes advantage of the "falling-film" phenomenon (discussed in Section 5.3.5) to establish a high heat transfer coefficient. The device appears similar to the GFX system except that segregated plumbing lines are required. Maintenance requirements are unknown. One potential advantage of this device, relative to the GFX, is that a greater thermal mass of potable water may be stored in the concentric tank which may improve performance, although this needs to be confirmed

The Aqua-Thermal system comes in three sizes ranging in price from $675 to $900. An additional $100 worth of materials, and 2 to 3 hours of time, is required for installation. The manufacturer claims that the device will typically reduce the annual DHW energy consumption by about 50%. It is not known whether independent test results are available or whether any sales have been achieved (Bedard, 1997).

### 5.3.2 Drain Gain

The Drain Gain system was developed by Winston MacKelvie of Knowlton, Quebec and is being marketed by Drain Gain Technology Inc. It uses a novel type of modified storage tank/heat exchanger, shown in Fig. 2. The plastic storage tank contains two horizontal spiral coils - one for the potable water (at the top) and the other for the greywater (at the bottom). The coil tubes are dimpled (referred to as the "PebblePipe"), a feature which the manufacturer claims retards development of the boundary layer thereby enhancing heat transfer. A secondary benefit is that this supposedly reduces sludge build-up by increasing turbulence within the tubes. The tank itself is filled once with clean water which provides both the thermal mass and the heat transfer medium. Since the greywater is contained in a pipe, sludge build-up is retarded or eliminated. The design also creates a thermal diode effect. If the greywater in the bottom coil is warmer than the water at the bottom of the tank, then the tank water will warm and rise by natural convection. If the greywater is colder than the surrounding tank water, natural convection will not take place and only minimal heat will be lost. To reduce clogging of the (lower) greywater coil, an additional device (the "Xcluder") is installed in the drain/waste/vent (DWV) stack which is intended to restrict solid material from entering the greywater coil. However, the manufacturer still recommends that the greywater coil be cleaned once a week with a blast of mains water. An early prototype has been monitored for over 2 years with no major problems reported and the system is claimed to have provided 41% of the DHW load

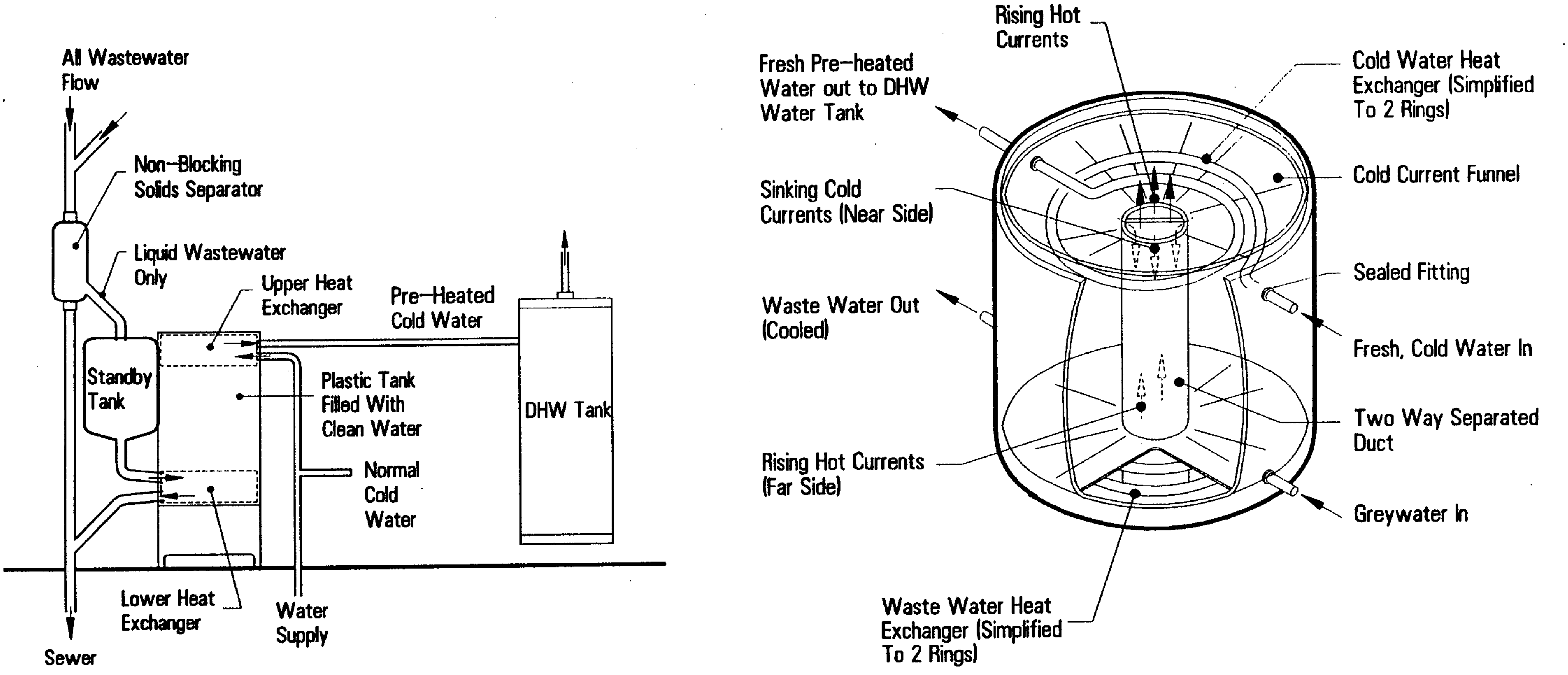


a) System Schematic

b) Aqua–Thermal Heat Exchanger

Aqua–Thermal

Fig. 1



a) System Schematic

b) Drain Gain Heat Exchanger

Drain Gain

Fig. 2

(although no information on the magnitude of the load was available). A small undersink unit intended for dishwashers is presently under development.

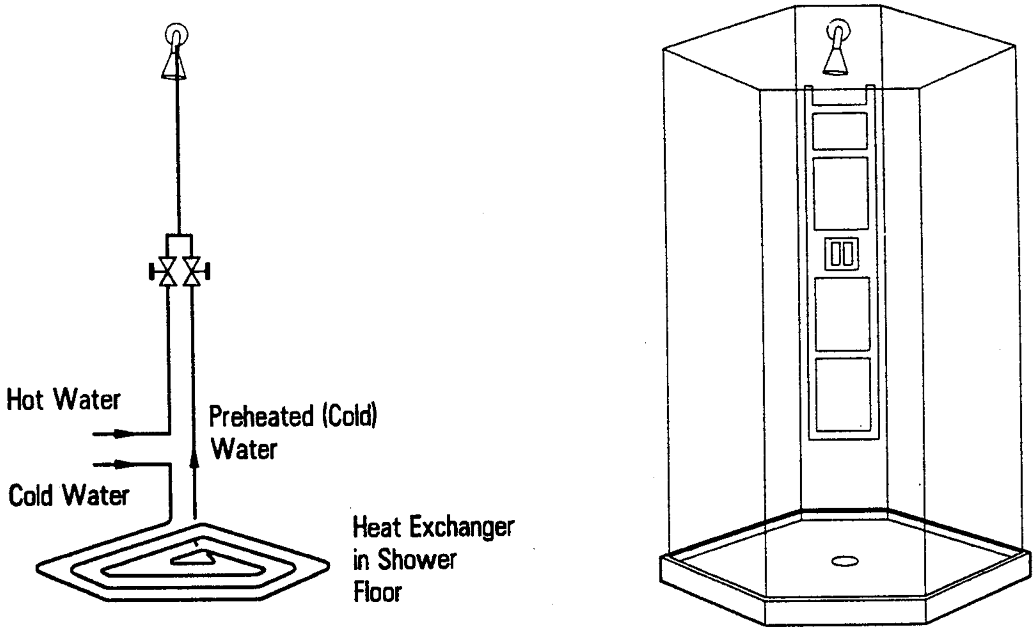
The Drain Gain is available in various sizes for both residential and commercial applications although the manufacturer appears to be concentrating on the commercial market. The suggested price for a residential model is approximately $600, with about 2 to 3 hours of installation time required (MacKelvie, 1997a and MacKelvie, 1997b).

### 5.3.3 HRS (Heat Recovery Shower)

This system is produced by Heat Exchangers NF Inc. of Stephenville, Newfoundland and is a departure from most GWHR systems in that the recovery heat exchanger is integrated into a single end-use (the shower). As shown in Fig. 3, the HRS consists of a corner shower stall with a spiral tube heat exchanger in the plastic floor. Incoming potable water passes through the HRS where it picks up heat from used warm shower water flowing over the floor. This preheated water is supplied to the "cold" sides of both the shower and the DHW tank. Placement of the heat exchanger below the floor is intended to reduce discomfort which might be caused by the user standing on a cold shower floor. The heat exchanger coil is cleaned by lifting the shower floor and hosing down the coil; the required cleaning frequency is unknown. The unit also includes a unique, combined microprocessor/valve/showerhead which is intended to control and conserve the shower's water flow and also control the temperature of the delivered water. No thermal storage is provided. Three units have been installed since late 1992. A monitoring program has been in the planning stages for some time to better define the system's performance, but as of this date no independent monitoring has taken place. The unit is reported to have a steady-state heat recovery capability of about 70%.

The economics of the HRS system are, to an even greater extent than other GWHR system, dependent upon the application. Obviously, the savings will be determined by the frequency and amount the shower is used. The system would be best suited to larger families and dormitory-type applications with a high utilization. Part of the rationale behind the product is the manufacturer's belief that traditional DHW conservation devices, such as low-flow showerheads, are not as effective in the long term as laboratory testing suggests because of homeowner intervention (such as converting back to a standard showerhead after a few months, taking hotter and longer showers or using higher faucet settings). This is a rather critical point from a DHW conservation perspective and while there is not a great deal of hard research to support or challenge the argument, there does appear to be an increasing amount of anecdotal evidence to support this contention.

The manufacturer is presently attempting to place the necessary financing and production equipment into place. The HRS is sold as a complete shower stall installation at prices which range from $1,765 to $2,165. The incremental cost of the heat recovery portion of the unit is about $400 (Lucking, 1997). From a marketing perspective, the biggest problem which the HRS will face is that they are attempting to compete not merely against manufacturers of GWHR systems, but against existing manufacturers of shower stalls.



a) System Schematic

b) Shower Installation

Heat Recovery Shower (HRS)
Fig. 3

These tend to be large firms with considerable resources, distribution networks and established reputations. The heat recovery component of the HRS shower is a relatively small part of the overall cost and its success is intrinsically tied to that of the shower stall.

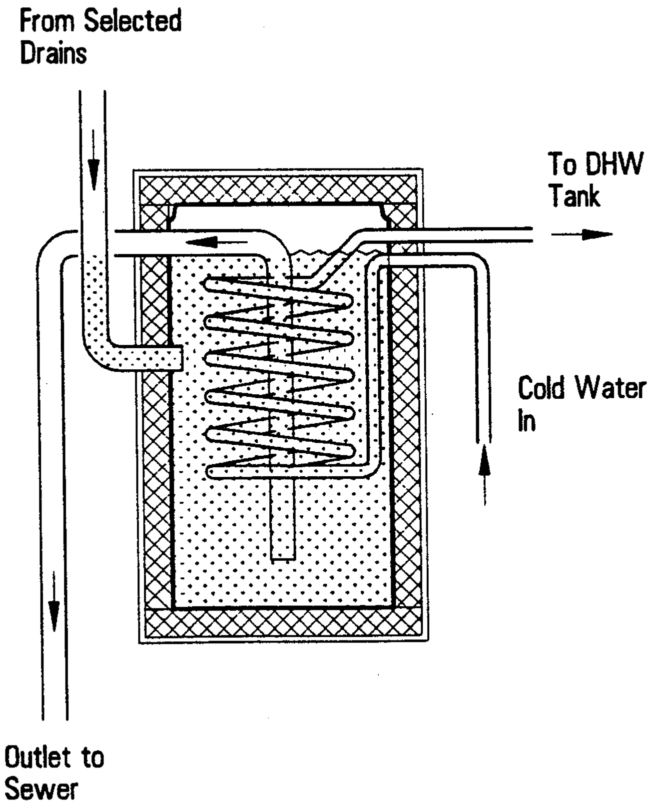
### 5.3.4 Earthstar Energy Systems Greywater Heat Reclaimer

Earthstar is an established manufacturer of residential radiant floor and ceiling heat systems based in Waldoboro, Maine, USA. Their GWHR unit (see Fig. 4) is a fairly conventional, combined storage tank/heat exchanger which uses a 50 US gallon insulated holding tank with an internal potable water preheat coil, possibly manufactured from cross-linked polyethylene tubing. Based on the manufacturer's literature the system appears to use a single-wall heat exchanger which could create code approval problems. It is intended to handle all of the major greywater flows in a house although the manufacturer does recommend segregated plumbing for high solids-content flows. An interesting feature of this system is that the recommended maintenance consists of pouring a litre of organic microbe enzyme into the unit twice a year to control sludge build-up. The enzyme is reported as being environmentally safe. The manufacturer claims that the unit can supply 30% of a typical residential DHW load, although no monitoring, costing or production data were available (Earthstar, 1997).

### 5.3.5 Vaughn GFX Waste Heat Recovery System

The GFX was developed and patented in 1985 by Carmine Vasile, CEO of WaterFilm Energy Inc., and is manufactured and marketed by the Vaughn Manufacturing Corp. of Salisbury, Massachusetts, USA, an established manufacturer of residential hot water tanks, control systems and related equipment. Vaughn is probably the only North American company which can legitimately claim to have a residential GWHR system in large scale production. As shown in Fig. 5, the unit is basically a counterflow heat exchanger consisting of a copper preheat coil wrapped around a section of copper plumbing stack. The preheat coils are available in 13 mm and 19 mm diameters (1/2" and 3/4") and the greywater stacks in 8 cm and 10 cm (3" and 4") diameters. The entire assembly is installed in a vertical section of the house's DWV stack (Vaughn, 1997; Carney, 1997; Vasile, 1997; Energy Design Update, 1996).

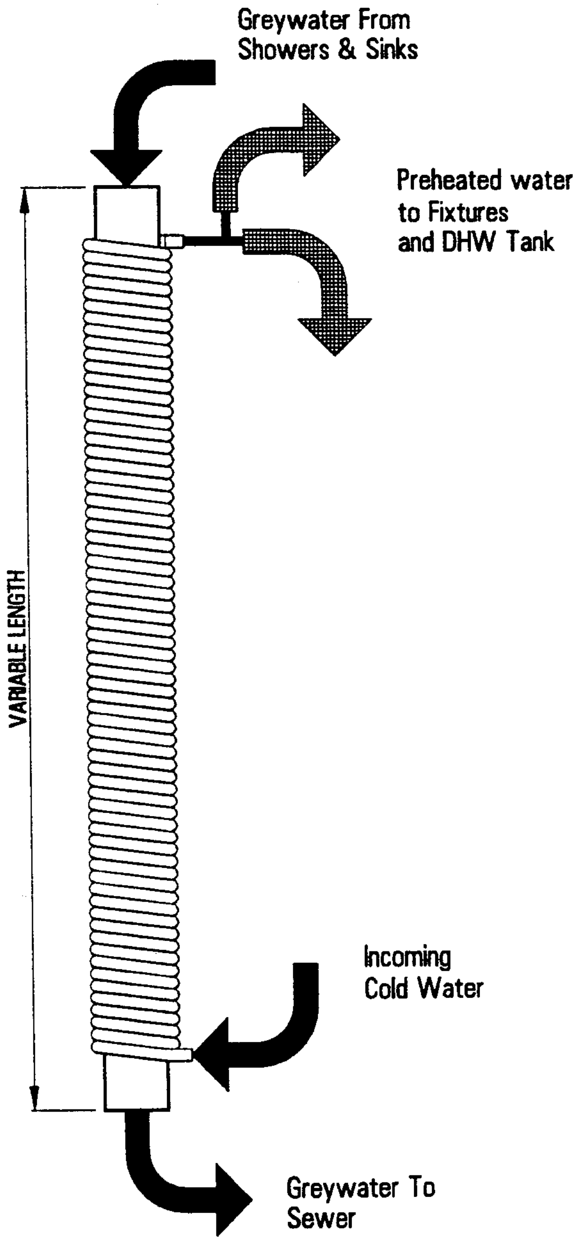
The standard configuration for the GFX, which the manufacturer refers to as an "equal flow" arrangement, is shown in Fig. 6 a). Greywater flowing down the DWV stack preheats the incoming potable water in the preheat coil which is then plumbed to both the water heater and the cold water line supplying the house's plumbing fixtures. All the water used in the house (with the possible exception of that used outdoors) passes through the GFX and is thus free to recover any heat which may be available from the greywater. The term "equal flow" is used because the greywater and potable water flow rates through the GFX are equal under simultaneous flow conditions. The advantage of this approach is that for applications with simultaneous flows, such as a shower, more energy can be recovered because the potable water flow rate through the preheater is larger than would occur if only the water to the DHW tank were being preheated. The thermodynamic advantages of plumbing the preheater to both the DHW tank and the plumbing fixtures can be significant. One disadvantage of the equal flow



Insulated Holding Tank

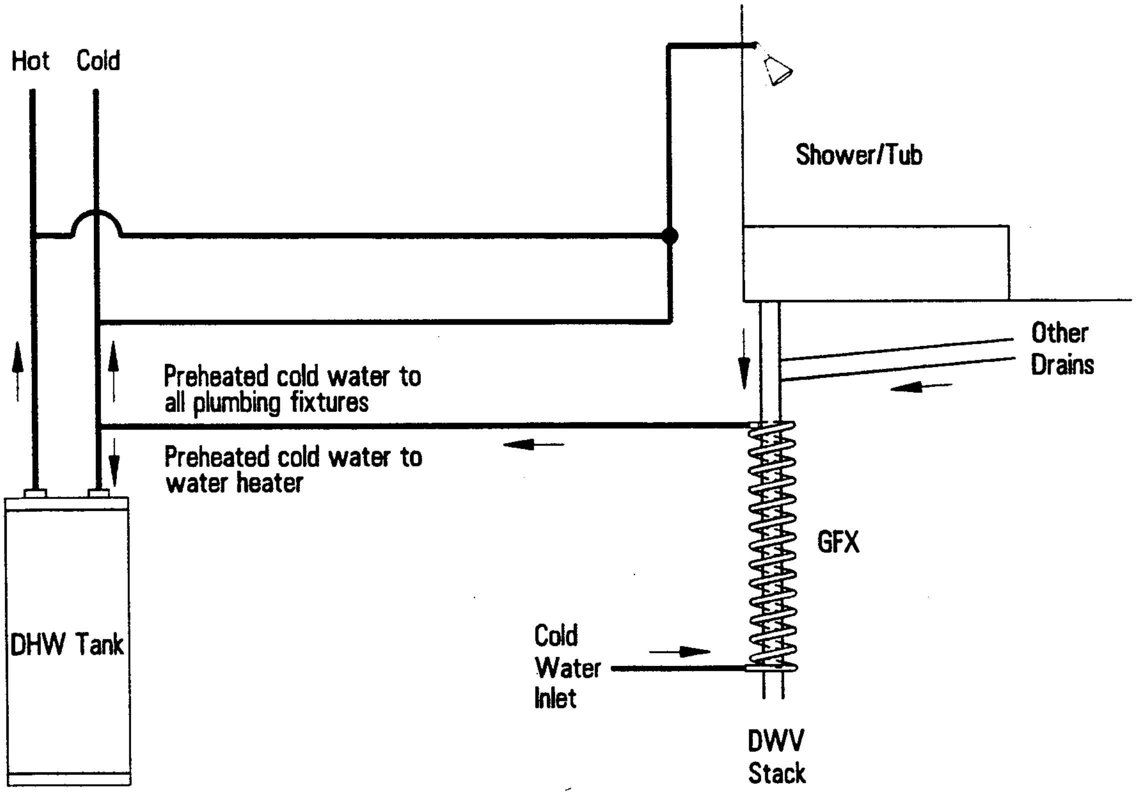
Earthstar GHR

Fig. 4

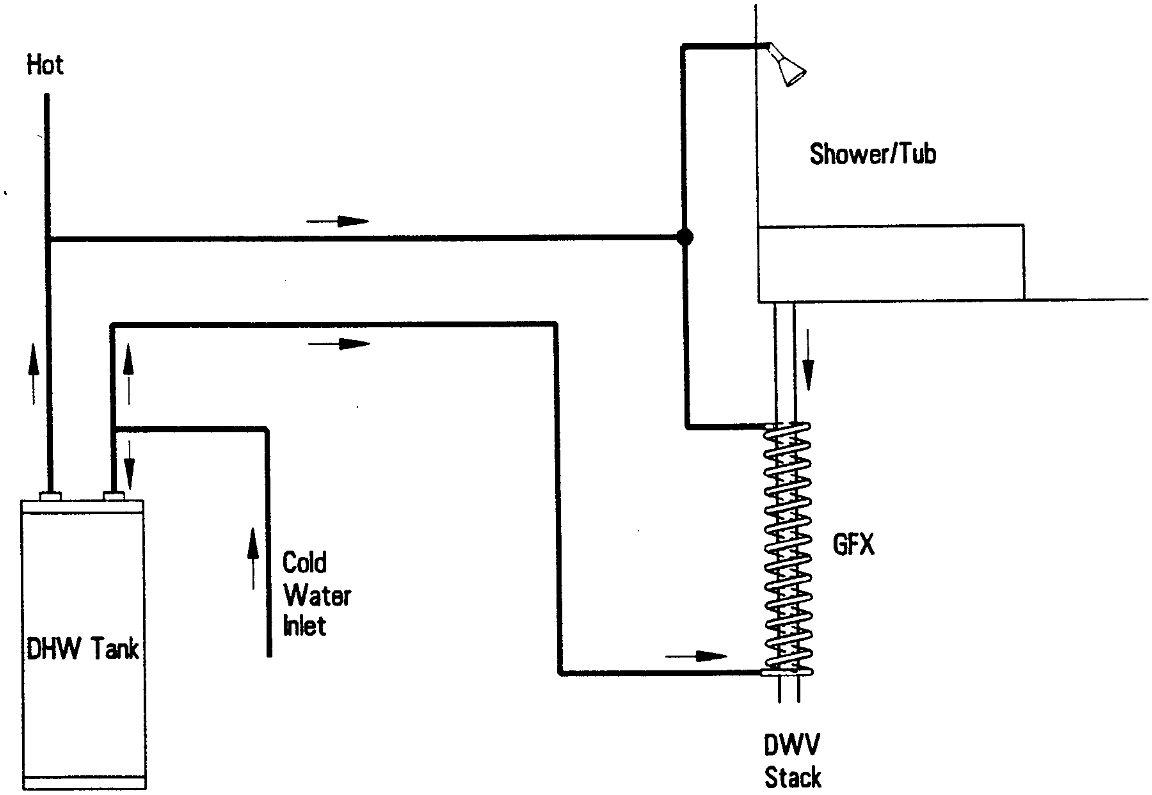


Vaughn GFX

Fig. 5



a) Equal Flow



b) Unequal Flow

GFX Installation Configuration
Fig. 6

arrangement is that all the cold water supplied by the plumbing system is preheated whenever warm or hot greywater is flowing down the stack. For example, a cold glass of water could not be obtained from the taps whenever someone was taking a shower. Given the other benefits of the system, this is viewed as a relatively minor inconvenience.

The GFX can also be installed in what the manufacturer refers to as an "unequal flow" configuration, Fig. 6 b). In this case, only the cold water supplied to the fixture(s) is preheated, and the greywater and potable water flow rates through the GFX are normally not the same. The cold water supplied to the DHW tank, which is eventually heated by the tank, does not pass through the GFX. Although less heat will be recovered using an unequal flow configuration, it may be more appropriate for installations where significant physical separation exists between the water heater and the DWV stack or where preheating for only a single fixture (such as a shower) is required.

No thermal storage is included in the GFX system (other than the small amount of water in the preheat coil) and significant heat transfer only occurs when there are simultaneous greywater and potable water flows. The manufacturer claims that very high heat transfer coefficients can be achieved because of what is termed the "falling film" phenomenon. As the greywater flows down the vertical DWV stack, it has a tendency to adhere to the walls of the stack in a thin film, rather than falling directly down the middle. In fact, "GFX" stands for *gravity film exchange*. The manufacturer reports that the water film thicknesses range from 0.30 mm to 0.69 mm (0.012" to 0.027") and the overall unit heat transfer conductance is approximately 2,500 $W/m^2{\bullet}{}^\circ C$ (440 $Btu/hr{\bullet}ft^2{\bullet}{}^\circ F$) (Waterfilm Energy Inc.). This permits very efficient heat transfer through the wall of the pipe.

The main advantage of the GFX system is that it is a zero maintenance device. Although some sludge build-up may occur, it should be no more than that which occurs with a standard plumbing stack. While heat is removed from the greywater by the GFX (which can increase sludge build-up) the greywater is moving at a relatively high velocity. Of the hundreds of units installed to date, there have been no reported maintenance problems. Also, the fact that the unit is made from copper should help to prevent sludge formation because copper's natural toxicity to microorganisms makes it less susceptible to organic growth than PVC, galvanized steel or cast iron. As discussed above, the need for regular maintenance is one of the greatest potential obstacles to the commercialization of GWHR technology and the GFX system eliminates this problem.

Compared to other GWHR systems, there is a relative abundance of performance data available on the GFX although some of it has been generated under non-representative conditions. The most extensive testing conducted to date was performed by Crossman of Old Dominion University of Norfolk, Virginia (1996). He carried out laboratory evaluations of the GFX installed in a test apparatus which replicated the operation of a shower. Using the 1.5 m (5') F-60 model, Crossman found that the GFX reduced the DHW load for the shower by an average of 52%. The calculated Energy Factor for the water heater with heat recovery was between 1.49 and 1.71, representing an increase of 57% to 73% over the standard resistance water heater alone. However, this test protocol in which only a shower load was used is not representative of a typical household DHW usage schedule since the greywater and potable water flows occur simultaneously - a near ideal application for a device like the GFX. This would not accurately reflect the performance under higher volume, batch flows. The higher flow rates would also create thicker water films and the energy flux would be greater resulting in a lower percentage of the available energy being recovered.

A field testing program was also recently completed by Northeast Utilities in Hartford, Connecticut who installed a GFX system in a typical home occupied by a family of three (Johnson, 1997). Monitoring showed that the system saved about 20% of the DHW load, significantly different from the Old Dominion results. Apparently this is due to two factors. In the Northeast Utilities test, the GFX was not installed according to the manufacturer's instructions, specifically it was not plumbed in an "equal" flow configuration (as described above) and thereby did not take full thermodynamic advantage of the greywater. The manufacturer estimated that had the system been properly connected in the trials, the savings would have increased from 20% of the DHW load to 37% while Northeast Utilities estimated it would have increased to about 25%. The other difference between the two sets of tests is that the Northeast Utilities testing was conducted in an actual house in which both batch and simultaneous flow loads occurred.

Additional testing on the GFX system is underway by the National Association of Home Builders' Research Centre and by utilities in Minnesota, Alabama and other areas (Vasile, 1997). With the sponsorship of five electric utilities, the U.S. Dept. of Energy and the National Association of Home Builders, a number of systems will be installed in houses in the utilities' service areas and monitored over a multi-season period to better assess energy savings.

A particularly good application for the GFX system would be in a high occupant density, high rise building such as a apartment block or condominium. Since there are many occupants there would be a natural diversity of water use and greywater flow schedules. The frequency with which simultaneous flows occur would be much higher than in a standard house thereby reducing the limitations created by the absence of thermal storage.

Since there is no storage or segregated plumbing, the installed cost of the unit is relatively modest. The manufacturer's list prices range from $180 to $590 (US $), as of August, 1997. The unit is available in over a dozen sizes ranging in length from 0.8 m to 1.7 m (2.5' to 5.6'). Installation time in a new house is estimated at about 1 hour and a little longer in an existing structure. The installed cost of the system for the Northeast Utilities tests was approximately $300 (US). However, this includes about 3 hours for installation, higher than normal because it was a retrofit situation. The system is also being promoted for commercial, industrial and agricultural applications. Since the GFX was introduced in early 1997, hundreds of systems have been installed. One notable example is the Toronto Healthy House, which had a unit installed in late 1996. No monitoring has been performed to date (Hart, 1997).

## Table 8
## Summary of Commercially Available Residential GWHR Systems (1998)

| Product | Description | Status | Advantages | Disadvantages |
|---|---|---|---|---|
| Aqua-Thermal | Single-component device installed on a separate drain line. | Commercially available, although production volume is unknown. | Believed to include a small amount of thermal storage. | Requires segregated plumbing lines. Maintenance requirements unknown. |
| Drain Gain | Uses a novel combined thermal storage/heat transfer tank; unit is installed on DWV stack and uses special device to exclude solids. | Commercially available, although production volume is unknown. | Includes thermal storage. Does not require segregated plumbing lines. | Requires regular maintenance. |
| Earthstar Energy Systems Greywater Heat Reclaimer | Relatively conventional design using a 50 U.S. gallon thermal storage tank. | Commercially available, although production volume is unknown. | Includes thermal storage. | Requires segregated plumbing lines. Believed to use a single-wall heat exchanger. Requires regular maintenance. |
| Heat Recovery Shower (HRS) | Point-of-use device which uses a heat exchanger in the floor of a shower stall to preheat the shower water. | Commercially available, although production volume is unknown. | Does not require modification to house's plumbing system. | Does not include thermal storage. Only recovers heat from a single end-use. Requires regular maintenance. Only available as part of a complete shower stall. |
| Vaughn GFX | Single-component heat exchanger installed on DWV line. | Commercially available, in large-scale production. | Relatively low installed cost. Easy installation. Requires no maintenance. | Does not include thermal storage. |

# SECTION 6

# MARKET ANALYSIS

## 6.1 MARKET APPLICATION

The market for residential GWHR systems can be broadly classified into two groups: new houses and existing homes. The new house market is the smaller of the two but from a technical perspective is a better application for most forms of the technology. Installation costs in a new home would be lower than those in an existing structure, especially if the GWHR system requires segregated plumbing or significant modifications to the plumbing system. In a new home, changes to the design of the plumbing system are relatively straightforward and can be accomplished with modest cost and inconvenience. Allocating space for a storage tank, if included, would also be easier in a new home. If segregated plumbing is not required then the technical suitability of the two markets becomes more comparable. GWHR systems which attach directly to the DWV stack and do not contain a separate thermal storage tank, such as the Vaughn GFX, would probably be the best types to use in a retrofit situation. In a new home, any type of GWHR system can be considered.

Table 9 summarizes some basic data on the number of existing houses in Manitoba and Canada and the number of new starts in 1996. It also includes comparable data for R-2000 houses since this is a potential market for residential GWHR systems (discussed below).

**Table 9**
**Housing Statistics**

| | R-2000 Houses[1] | | Total (Singles and Multiples)[2] | |
|---|---|---|---|---|
| | Existing | Housing Starts (1996) | Existing | Housing Starts (1996) |
| Manitoba | 270 | 27 | 344,000<br>(1991 data) | 2,318 |
| Canada | 7,800 | n/a | 10,200,000 | 124,713 |

Sources:
1. R. Romas, 1997.
2. CMHC, 1997.

## 6.2 MARKET PENETRATION

The current level of market penetration by residential GWHR systems in Canada is negligible, with only a handful of systems installed at present. Despite a few false starts at commercialization over the last decade, off-the-shelf products did not become available until last year (1997). However, a rapid increase in the number of installations could occur in the near future. A similar situation exists in the United States, although with the introduction of new products, there are likely hundreds of units installed, with annual production in the range of (perhaps) hundreds per year.

There are several explanations for the low market penetration to this point. First, there has been the absence of a readily available, off-the-shelf product. Although several GWHR systems have been constructed for demonstration projects on a one-off basis, commercially available systems have only recently appeared. Second, high costs - or the perception of high costs - for residential GWHR systems and the belief that they have a poor cost-effectiveness may have discouraged manufacturers from developing products. However, as discussed below, cost-effectiveness can be a poor justification for energy conservation products. In fact, improved comfort and the other benefits can be much more marketable reasons for consumers to purchase GWHR systems. Finally, the perception of "sewage contamination" may have dissuaded manufacturers from developing the technology if they believed that the marketplace would reject the product for that reason.

## 6.3 MARKETING RESIDENTIAL GWHR TECHNOLOGY

"It is one thing to build a product, quite another to market it successfully" (Olmstead, 1997). As previously noted, most residential products which deliver energy savings have been marketed on the basis of the dollar savings which they produce. This approach was used, for example, in the early days of the R-2000 Program. However, the experiences gained over the last decade provide some valuable insights into how residential GWHR systems might be successfully marketed.

Perhaps the most important lesson learned is that technology by itself is difficult to sell, rather it is the benefits which convince the consumer to purchase the product, i.e. "sell the benefits not the features". To illustrate, during the formative years of the HRV industry, manufacturers attempted to sell their products on the basis of energy savings (assuming the comparison was being made to a house with an equivalent ventilation rate but without heat recovery). By and large, their analyses were technically correct, and were supported by government-funded research studies analyzing ventilation system performance. The only problem was that it did not sell. Most consumers (early adopters aside) either did not understand the intricacies of the analyses or were unmoved by their conclusions. What ultimately did work for the manufacturers was shifting their marketing strategy from "energy savings" to "providing clean air". They successfully positioned their products so they were seen as providers of a healthy indoor environment. Energy savings were still acknowledged but they were now treated as a pleasant by-product rather than the primary rationale for purchasing the product.

Another valuable lesson from conservation program experiences is that one of the biggest problems which any new product faces, particularly one which is technologically based and which is not competing against an existing product, is simply educating the marketplace about its existence. Marketing has to include explaining that the product exists, what it does, the benefits which it provides, and of course how the manufacturer's product provides all of these. The experiences which other technologies have faced as they entered the marketplace have shown that the effort, and cost, to educate the consumer can exceed that required to develop the product. In the case of residential GWHR systems, the typical builder, designer, homebuyer or homeowner can be regarded as totally ignorant of the concept or the existence of commercially available products. While educating the world may be a noble task, it is a very onerous one. At present, there are only a handful of systems commercially available in North America, and their manufacturers are tasked with this educational responsibility. The author recalls a comment made to him in the early 1980's by the first manufacturer in North America to market commercial blower doors (used for performing airtightness tests on buildings). A new competitor had recently entered the marketplace and the author commented that this would make life more difficult for him. The manufacturer disagreed emphatically and argued that the presence of a competitor would actually help his business because the biggest obstacle he faced was lack of awareness about exactly what a blower door was, what it was used for, etc. With a competitor, there were now twice as many firms providing this consumer education. He felt that whatever market share was lost to the competitor would be more than made up for by an expanded overall market size.

Another lesson which can be gleaned from the housing and HRV industries is that new products can be commercialized with the greatest success in niche markets (Russell, 1997). It is natural to try to produce a universal product which will work in all applications and under all circumstances. However, few products possess such breadth and scope and even if they do, the necessary development effort would probably exceed the capabilities of all but the most resource-rich firms. Instead, if one or two specialized markets can be identified and a well-designed product developed specifically for them, a foothold can be developed which not only provides a cash flow but also establishes the product as "real", giving the firm some inertia and generating revenues for on-going development.

## 6.4 MARKET POTENTIAL

Since the present level of commercialization of GWHR systems is so small, it is very difficult to make firm predictions about the size of the potential market. Rather, it is more realistic to identify potential niche markets which would benefit the most from the product. As a start, Table 10 summarizes the types of application characteristics which would be most desirable for residential GWHR systems. Examining these characteristics, some potential markets for residential GWHR systems become evident.

### 6.4.1 The R-2000 Market

The most obvious market would be R-2000 houses since their designers and owners have a greater concern for energy-related issues and would likely be more receptive to a new technology. Although the R-2000 market is relatively small, it could be a useful means of exposing GWHR technology to the broader market. Most of the energy conservation features incorporated into R-2000 houses are intended to reduce the space heating load. DHW conservation features generally consist of an energy efficient water heater, low flow showerheads and faucets. While the total DHW load is smaller in an R-2000 house, the fraction of the total energy load attributable to water heating is larger than in conventional construction.

**Table 10**
**Desirable Application Characteristics for GWHR Systems**

1. Expensive DHW energy source
2. High DHW consumption
3. Poor water heater efficiency
4. Large family size
5. Limited potential for hot water conservation
6. DHW system which requires two tanks
7. Family willingness to adopt a new technology
8. Applications where control of electrical demand is important
9. Applications where multiple households use common greywater plumbing
10. Ability to easily separate warm and cold wastewater streams

Houses which use electric DHW heating would be excellent, potential candidates for GWHR systems because of the higher cost of electricity. For houses which use natural gas water tanks, the R-2000 Program requires that non-naturally aspirated tanks be used because of concerns about combustion spillage and backdrafting. In these cases, a GWHR system coupled with an electric tank may be an attractive alternative since non-naturally aspirated gas DHW tanks tend to be significantly more expensive than conventional DHW tanks, yet provide only modest improvements in efficiency (see Table 6).

### 6.4.2 The Multi-Unit Residential Market

Duplexes, multi-plexes, condominiums, apartment blocks, etc. would also be excellent applications for residential GWHR technology if the greywater plumbing is common to more than one dwelling unit. Where several units drain greywater through a common stack, the total greywater energy flux will be much higher than in a single, detached house. The more units draining into a single DWV stack, the greater the potential savings per installed GWHR unit. In multi-storey buildings, the DHW and greywater flows are also more frequent so there are greater opportunities for energy recovery. As the DHW and greywater flows become more evenly distributed over time, the need for thermal storage declines. This would provide an opportunity to lower costs by reducing the amount of storage (per dwelling unit) or eliminating it totally. However, to effectively utilize the recovered energy, the building must use a central DHW heating system. Multi-unit, residential buildings in which each dwelling unit has its own hot water heater would not have this opportunity for centralized heat recovery. It is also important that GWHR systems used in multi-unit buildings should be designed specifically for that application. A unit designed for a detached house may not work as effectively as a purpose-designed system (although it should still provide some benefit).

### 6.4.3 The Electric Utility Market

Another potential market for residential GWHR systems would be those electric utilities who wish to compete more effectively against natural gas and oil utilities/companies. Examining the potential markets for GWHR systems, perhaps the biggest opportunity may be that created by the combination of electric DHW heating and GWHR as an alternative to natural gas, or oil, water heating. The price of natural gas is generally lower than electricity, however the efficiency of most types of gas heaters is poor. The Energy Factors for naturally aspirated, power-vented and direct-vent, natural gas water heaters range from approximately 0.48 to 0.59 with an average of about 0.55. Further, the Energy Factor does not account for the extra energy needed to condition the outdoor air required by the hot water heater. Although natural gas usually has a price advantage relative to electricity, the low efficiency and make-up air requirements of gas DHW heaters considerably reduces this advantage in most instances.

Determining the impact of combustion-based water heaters on the space-heating load is compounded by the limitations of the computer programs currently used for modelling building energy performance. For example, in the most recent edition of HOT2000 (identified as Version 7.15 and with a release date of December, 1997 or later), the presence of the water heater vent is accounted for by entering a non-zero water heater vent diameter which is then used by HOT2000 to increase the Equivalent Leakage Area of the building envelope - i.e., the house becomes leakier for analysis purposes. If the water heater is co-vented with another appliance such as a furnace, then the water heater vent diameter is set to zero. Thus, the most recent version of HOT2000 V7.15 attempts to account for the additional air required by the water heater (although the adequacy of these algorithms is unknown). Unfortunately, versions of HOT2000 released prior to December, 1997 (including those which are identified as Version 7.15) do not have this feature. Using these older versions to evaluate DHW water heater and heat recovery alternatives will generate results with a systematic bias against electric DHW heating.

Significant improvements in natural gas water heater performance are only achieved once a power-vented, sealed combustion unit is used, such as the Polaris water heater which has an Energy Factor of 0.86. This type of tank uses two heat exchangers to cool the products of combustion to a sufficiently low temperature that much of the water vapour in the flues gases condenses, thereby releasing latent heat. They are similar to condensing furnaces which have been on the market for approximately 15 years. Two or three different models are presently available in Canada. However, power-vented, sealed combustion water heaters are significantly more expensive than naturally aspirated water heaters. To reduce this price handicap, most are used to supply both the space and DHW heating loads. Unfortunately, this introduces operational penalties if a GWHR system is also used since the efficiency of condensing units decreases with increasing inlet water temperature. If the inlet water is preheated by a GWHR system, the water heater will not be able to operate as efficiently. Much, or all, of the benefit produced by the GWHR will simply be at the expense of the water heater. Also, because of the heater's higher efficiency the cost of water heating is much lower than it would be with a conventional water heater - meaning that the savings produced by the GWHR system would be diminished. A condensing gas water heater and GWHR system are generally a poor combination.

Table 11 compares the costs of delivered energy from a high efficiency electric hot water tank combined with a GWHR system, to those using a natural gas tank. Water heating system efficiencies were calculated using HOT2000 V7.15 and the appliance's Energy Factor. The range of purchased energy rates in Table 11 are representative of current prices in Canada, and include the current (Jan. 1, 1998) Winnipeg run-off rates for electricity (5.16 ¢/kWh) and natural gas (1.95 ¢/kWh$_e$ or 20.20 ¢/m$^3$). The electric water heater used in this analysis was a high efficiency, model with a standby loss of 65 W (i.e. the so-called Generation 3 "Gold" tank), which has an EF of 0.90. The percentage of the DHW load supplied by the GWHR system was varied in Table 11 from 0.20 to 0.50, to represent a range of GWHR system performance and applications. The lower value represents a system without storage meeting predominately batch loads whereas the upper value describes a well-designed system with storage. EF values for the natural gas water heaters ranged from 0.45 to 0.60, covering the performance of most tank types except the power-vented, sealed combustion type.

It is apparent from Table 11 that the combination of a high efficiency, electric water heater and a GWHR system could, in many situations, provide hot water at a rate competitive with natural gas systems due to the inherent efficiency of the electric tank/GWHR combination and the relatively poor efficiency of conventional gas water heaters. The electric tank/GWHR combination could also compete effectively against higher efficiency gas water heaters because the latter cost significantly more than conventional tanks yet provide only modest improvements in performance (unless the most sophisticated - and expensive - type of tank is used, i.e. power-vented sealed combustion). For example, using current Winnipeg utility rates, the cost of delivered hot water from a conventional natural gas tank will be about 4 ¢/kWh$_e$ whereas an electric tank coupled with a GWHR system supplying 30% of the DHW load could also supply hot water at 4 ¢/kWh.

Of course, GWHR systems can also be used with natural gas water heaters to reduce their operating cost. However, the percentage savings will generally be less than if the GWHR system were used with an electric tank since the energy consumed by the pilot light (if one is used) represents a fixed load that would not benefit from heat recovery. Also, the extra space heating load created by the draft diverter air would be largely unaffected. Depending on the rate structure used by the gas utility, the dollar savings during the non-heating season may be less than expected if there is a fixed charge for the first block of gas used each month. If the water heater is the only appliance using natural gas during the non-heating season, the reduction in energy produced by the GWHR system may effectively be "lost" in the fixed charge. This would not occur with an electric tank since there are always other uses of electricity in the house.

A long-life, high efficiency electric water heater (with a life expectancy of several decades), combined with a GWHR system with an equivalent life span would offer a very attractive "life-long" package. In contrast, conventional water heaters, including natural gas tanks, generally last little longer than a decade. The capital cost of the high efficiency electric tank/GWHR combination would, of course, be greater than those of a simple conventional tank. However, its life-cycle costs would likely be comparable given that perhaps two or three replacement tanks would have to be installed during the lifespan of one electric tank/GWHR unit.

**Table 11**
**Comparative Cost of Delivered Hot Water For Electric Tank/GWHR Systems and Natural Gas Tanks**

| Electric Tank (EF = 0.90) & GWHR Combination System | | | | |
|---|---|---|---|---|
| Cost of Purchased Energy ($/kWh) | Percentage of DHW Load Supplied by GWHR System | | | |
| | 20% | 30% | 40% | 50% |
| 0.050 | 0.045 | 0.040 | 0.035 | 0.030 |
| **0.0516** | 0.046 | 0.041 | 0.036 | 0.031 |
| 0.060 | 0.054 | 0.048 | 0.042 | 0.036 |
| 0.070 | 0.063 | 0.056 | 0.049 | 0.042 |
| 0.080 | 0.072 | 0.064 | 0.056 | 0.048 |
| 0.090 | 0.080 | 0.071 | 0.062 | 0.053 |
| 0.100 | 0.089 | 0.079 | 0.069 | 0.059 |

| Natural Gas Tank | | | | |
|---|---|---|---|---|
| Cost of Purchased Energy ($\$/\mathrm{kWh}_e$) | Tank Energy Factor | | | |
| | 0.45 | 0.50 | 0.55 | 0.60 |
| 0.015 | 0.032 | 0.029 | 0.026 | 0.024 |
| **0.0195** | 0.042 | 0.038 | 0.034 | 0.032 |
| 0.020 | 0.043 | 0.038 | 0.035 | 0.032 |
| 0.025 | 0.053 | 0.048 | 0.044 | 0.040 |
| 0.030 | 0.064 | 0.058 | 0.053 | 0.048 |

Nonetheless, the biggest competition for the electric tank/GWHR option is the standard naturally aspirated tank - assuming they continue to remain available - because of its low initial cost. However, if they are taken off the market due to safety concerns about combustion spillage/backdrafting or because of their inherent inefficiency (as happened with naturally aspirated furnaces), a huge potential market could emerge for the electric tank/GWHR option.

### 6.4.4 The Remote Location Market

Remote locations, such as those in the Northwest and Yukon Territories and other isolated areas, have also been suggested as potential niche markets for GWHR systems because of their extremely high energy costs (Russell, 1997). DHW heating is often several times more expensive in these locations compared to southern Canada so payback periods for GWHR systems should be very short. However, reliability and low-maintenance are critical in these areas since spare parts and experienced tradesmen (for speciality items) are often not readily available. GWHR systems suitable for this market would have to be inherently fail-safe such that breakdown of the GWHR system would not imperil the DHW or other systems. Remote locations have occasionally served as proving grounds for new technologies in the residential market. The rigors of the climate and the limited support network for maintenance has meant that a technology which could be made to work in these locations should be able to easily function in more populated regions. Although the potential size of this market is small due to the limited population base, it is one which could be well served by a reliable, properly-designed GWHR system.

## 6.5 IMPACT ON MANUFACTURING INDUSTRY

Commercialization of residential GWHR systems is just beginning so firm predictions of its impact on the manufacturing sector are difficult to make. However, examination of products of a similar nature, such as HRVs, can provide a few useful insights into what the future may hold. The first HRV manufacturers had to create three separate entities: a product, a company and an industry. Each of these has its own unique problems and it is probably fair to say that a product is easier to create than a company, and a company is easier to establish than an industry. Anything which can simplify this task will expedite the successful adoption of a new technology. It is interesting to note that the system marketed by the largest manufacturer of residential GWHR systems (Vaughn) was developed by an individual but is being produced and marketed by an established, successful manufacturer of related products. This represents a pathway to commercialization which has a greater probability of success.

There could also be an impact on the testing industry similar to what took place with the HRV industry and the development of a test standard for that product. Establishment of a testing standard for GWHR systems could also lead to the creation of a Canadian test facility, similar to that created at ORTECH to test HRVs.

## 6.6 CURRENT PRICES

Table 12 summarizes the current, reported retail prices for the GWHR systems discussed in Section 5. Note however, that one of these - the Vaughn GFX - is in quantity production, so its costs can be treated as relatively firm. The other manufacturers have yet to reach this stage so their price data should be viewed as tentative.

Data on installation costs is somewhat limited. However, most manufacturers estimate that 1 to 3 hours is required to install a system, provided major modifications are not needed to the plumbing system. Additional plumbing materials would add $50 to $200 to the overall cost.

**Table 12**
**Current Price Data For GWHR Systems**

| System | Retail Price (Canadian dollars unless noted) | Comments |
|---|---|---|
| Aqua-Thermal | $675 to $900, depending on size | Price does not include installation. |
| DrainGain | $600 | Price does not include installation. |
| Earthstar | unknown | |
| HRS | $400 | Price shown is for the heat recovery component of the shower stall only; complete shower stall costs $1,765 to $2,165. Price does not include installation. |
| Vaughn GFX | $180 to $590 (US $), depending on size | Unit available in several sizes. Price does not include installation. |

## 6.7 CONSUMER ANALYSIS

### 6.7.1 Potential Benefits of Residential GWHR Systems

As summarized in Table 13, residential GWHR system can provide several benefits to the occupants of a home or to energy utilities. Energy savings are the most obvious and quantifiable benefit and they have usually been the justification for most GWHR installations. The magnitude of the savings vary with load, occupant lifestyle, system design, etc. but can roughly be expected to fall within the broad range of 10% to 60% of the existing DHW load. While greater savings are achievable, the incremental cost of capturing them are probably not justified. Despite the comments made earlier about the hazards of marketing energy savings, they nonetheless represent a significant benefit. Compared to other energy recovery technologies, such as HRV's, residential greywater heat recovery systems have the advantage of providing an energy benefit which may be more tangible to the consumer. No one has to be convinced that significant amounts of heat are wasted down the drain every time a shower is taken or a load of dishes is washed. Perhaps warm water, being more tactile than air, and easier to feel than heat loss through an opaque building element, can be more easily appreciated by the consumer. These benefits are also generated throughout the year, not just in the heating season.

A second benefit of GWHR systems is they increase the effective "First-Hour Rating" of the water heating system. This term describes the amount of hot water which the tank can deliver in 1 hour starting with a full load of hot water. Depletion of the hot water supply, termed a "runout" can be a problem, particularly with electric tanks since they take longer to recover than fossil fuel-fired tanks. Field testing has shown that water heater runouts are generally due to high flow rate, high volume draws imposed over a relatively short period of time (Hiller, 1996). Depending on the type of GWHR system, a significant portion of the energy contained in a high volume draw can be recovered within a short period of time and used to preheat the incoming potable water, thereby increasing the effective First-Hour Rating of the water heater.

**Table 13**
**Benefits of Residential GWHR Systems**

1. Energy savings
2. Increased First-Hour Rating of tank
3. Improved comfort due to slower temperature degradation at runout
4. Reduction of the coincident, peak demand
5. May permit a single tank to be used to meet a dual-tank load

A third benefit (although perhaps less significant), is that GWHR systems can improve comfort for someone showering by preventing the rapid drop in water temperature which occurs during runout. Although there is limited consumer experience to support this belief, GWHR systems moderate the effects of runout so that the temperature drop occurs over a longer time period. In fact, the amount of heat recovered by some types of systems increases under high-load conditions so the moderating effect is enhanced. The improvement in comfort which a GWHR system provides will depend on the type of system and its performance under simultaneous and batch flow conditions. As noted in Section 2, most comfort issues occur during simultaneous flow loads, such as showering, rather than batch flow loads. Therefore, a system unable to recover heat from batch flows may still be able to provide comfort benefits.

A fourth benefit is that GWHR systems reduce the coincident peak electrical demand, particularly for electrically heated houses. Although the data is limited, it is reasonable to assume that the heat recovery system would reduce the time period during which the elements were firing thereby lowering the frequency of coincident peaks. This would benefit the utility and, if a demand billing structure were used, the customer.

Finally, GWHR systems may offer an alternative to dual-tank systems for homes with large DHW loads. Since GWHR systems effectively increase the First-Hour Rating of the water heating system and recover more heat as the DHW load increases, it may be possible to substitute a GWHR system for the second tank. This would offer the immediate benefit of heat recovery, reduced stand-by losses (which would otherwise occur from the second tank) and perhaps lower capital costs.

Overall, the most significant benefits to the consumer will probably be the increase in effective water heater capacity. Comfort, having an "inexhaustible" supply of hot water and a more gradual cool down of the hot water temperature are all tangible benefits from the consumer's perspective. In particular, the fact that it takes longer to use all the hot water if heated recovery is included is very important. However, these theories need to be verified at the consumer level.

## 6.8 POTENTIAL OBSTACLES TO COMMERCIALIZATION

There are several potential obstacles which could slow or even foil commercialization of residential GWHR systems.

### 1. Lack of market awareness.

Greywater heat recovery is virtually unknown to the residential consumer and home builder markets. Successful marketing will require a significant effort to educate the public about the concept, in general, and specific products, in particular. This will require a considerable effort over a number of years since literally millions of potential consumers have to be reached and convinced. The magnitude of this challenge will be reduced somewhat as additional manufacturers enter the market, since their individual marketing efforts will combine to collectively educate the consumer.

### 2. Limited performance data.

At present, there is little independently generated information on the energy savings and other benefits which GWHR systems produce. Particularly lacking are third-party assessments, i.e. those conducted by organizations without a vested interest in the product. This problem is compounded by the absence of standardized testing procedures which makes repeatable testing and verification more difficult. Also, there is only a limited understanding of how to translate test results into reasonable predictions of system performance under "real-world" operating conditions.

### 3. Perceived Cost Effectiveness.

The R-2000 experience has demonstrated the difficulty of marketing energy savings on a purely economic, cost-effectiveness basis. Most consumers have little idea of the actual "payback periods" for their purchases, assuming economics is even a factor. Based on personal experience, most consumers would insist on payback periods for a GWHR system which are unrealistically short, while making other purchases for aesthetic, comfort, appearance or other reasons which provide no economic benefits. Establishment of a successful GWHR system, company or industry will require careful marketing so that the "payback trap" is avoided. The energy and dollar savings of a GWHR system can certainly be stressed, but only as one of a group of benefits. If, for example, "more hot water at no extra cost" is the benefit, then cost-effectiveness ceases to be an issue.

### 4. Health and safety concerns.

Perhaps the greatest threat to commercialization could arise if the market perceives (incorrectly) that there is a significant possibility of "sewage" contaminating their water supply. This issue must be managed very carefully to forestall an undeserved reputation. North American plumbing codes generally require that double wall heat exchangers (or the equivalent) be used to separate potable water supplies from wastewater. With this level of separation, plus the fact that the potable water is usually at a higher pressure than the greywater, the probability of contamination is remote. Nonetheless, some consumers may perceive the risk to be much greater and could, for example, attribute slight changes in the taste or smell of water (which occurs for other reasons) to the GWHR system. These concerns need to be addressed by detailed consumer education.

**5. Possible opposition by building officials.**

Building officials tend to be conservative by nature and may display some opposition to the use of GWHR systems because of the possible contamination problem. However, given a proper demonstration, and adequate documentation on the inherent safety features of properly designed systems, this should not pose a major or long-standing problem. The best way to address the concerns of building officials would be to establish a product standard for GWHR products (see below).

**6. Absence of standards.**

There are currently no standards which deal with residential GWHR systems. Aside from testing standards, there is also a need for product standards which set minimum requirements for health and safety issues, maintenance requirements, installation procedures, etc. Given the current state of the industry, this may be premature but will nonetheless have to be addressed if the industry is to become established. Once a standard is developed by a recognized standards association, building codes can reference it thereby meeting the concerns of building officials.

The establishment of testing and installation standards would also add credibility to the GWHR industry. Although most consumers have little understanding of what a standards label on a product means, its inclusion on a product increases their confidence in the product. It is worth noting that one of the factors which helped launch the HRV industry was the creation of a testing standard (CSA C-439) and a recognized Canadian test facility (at Ortech in Mississauga). The equivalent will be needed by the GWHR industry.

## 6.9 POTENTIAL PARTNERS/ALLIES/OPPONENTS

At present, there are only a small number of organizations in Canada with an interest in residential GWHR systems. Manitoba Hydro, as the primary supporter of this study, could benefit from the technology through its "No Worry" water heater rental program, or possibly through some other venue. These could be important because Manitoba Hydro's Demand Side Management (DSM) programs remain a critical component of their customer service and integrated resource plan, unlike many Canadian utilities who have eliminated their DSM programs. Natural Resources Canada, the second sponsor of this study, has an obvious interest in energy-saving technologies, particularly those which could be used in the R-2000 Program. Canada Mortgage and Housing Corporation also has an interest and is presently supporting a small number of GWHR demonstration projects.

As discussed above, GWHR technology may have the potential to give a marketing opportunity to electric utilities wishing to compete more aggressively against natural gas or oil water heating. In this case, the electric utilities would obviously be allies of GWHR technology.

Due to its very small presence in the current marketplace, GWHR technology does not have any specific "opponents" (other than obscurity), although some may develop in the future. As discussed, codes officials could raise opposition, however these are unlikely to be significant and can be dealt with through a product certification program designed to demonstrate the safety of the technology. In addition, the structure of building codes in Canada is changing to an "objective-based" format, away from the current prescriptive approach. This will provide codes officials with a greater ability to evaluate technologies which do not fit directly within the code structure but still meet the intent of the building code. It should also stimulate the intellectual initiative of codes officials by giving them greater incentive to consider and evaluate new ideas.

Of course, if GWHR technology were used by one group (such as electric utilities) to acquire market share at the expense of another group (natural gas utilities), the latter group might presumably become an opponent of the technology. The same could also be said for related industries such as the manufacturers of natural gas water heaters.

# SECTION 7

# ACTION PLAN

## 7.1 RECOMMENDATIONS

Residential greywater heat recovery systems have several potential benefits which could be attractive to homeowners, electric utilities and others. However, the knowledge base on GWHR system performance, costs and numerous practical considerations is very limited. These information gaps need to be filled, particularly for the benefit of potential users such as Manitoba Hydro.

The following recommendations are offered as an initial framework for the development of an expanded knowledge base. Some of these, such as monitoring of actual installations, could be implemented immediately. Others should only be considered if the developing knowledge base supports further activities. Some of these recommendations could be initiated by Manitoba Hydro, others by NRCan or other parties. The recommendations are:

1. **Conduct a workshop on GWHR systems for interested parties.**
   A workshop on residential GWHR systems should be organized and held to: establish a network of organizations and individuals with an interest in the technology, identify potential research, development and demonstration initiatives and to lay the groundwork for collaborative efforts among interested parties. (Note: a plan for this workshop has been prepared and delivered separately.)

2. **Establish a residential GWHR system monitoring and evaluation program.**
   More direct experience and documented performance is needed with GWHR systems, particularly with respect to the practical aspects of their operation. Manitoba Hydro should consider establishing a monitoring program to assess the performance of a small number of systems in actual houses. Any energy monitoring component would have to carefully planned to account for the dynamic nature of DHW loads, greywater flows, etc.

3. **Implement a pilot program to gauge consumer reaction to the technology.**
   Based on the outcome of the monitoring, Manitoba Hydro should consider implementing a pilot program to use GWHR systems in their "No Worry" water tank rental program.

4. **Evaluate the electric water heater/GWHR system option.**
   If the results of these activities are positive, Manitoba Hydro could consider exploring the electric water heater/GWHR option as a means of competing against natural gas water heating for market share.

5. **Develop design and installation guidelines.**
NRCan, and possibly others, should develop design tools, installation guidelines, etc. for GWHR systems including the tools for predicting savings in R-2000 houses.

6. **Develop training programs.**
A plan should be developed to educate building codes officials, builders and consumers about residential GWHR systems, their benefits, potential problems and costs.

7. **Develop a testing standard.**
A laboratory-based testing standard should be developed which describes procedures for determining the thermal performance, and other performance characteristics, under standardized and representative conditions. This standard could be based on the work by Perlman and Mills but with an updated version of their simulated-use test so as to better reflect the actual flow characteristics of greywater and potable water flows.

8. **Develop a product standard.**
Once a sufficient knowledge base has been developed, a product standard should be developed which addresses requirements for health and safety issues, design techniques, installation procedures, maintenance requirements, etc.

# SECTION 8

# CONCLUSIONS

## 8.1 HOT WATER CONSUMPTION PATTERNS

Two of the most critical variables which affect the technical and economic viability of GWHR systems are the size, and flow characteristics, of the DHW load. Applications which are the most desirable have large hot water loads with flow patterns which closely match the performance capabilities of the intended GWHR system. Various researchers have studied residential DHW load patterns and reported average, annual gross energy consumption values ranging from 3,770 to 5,760 kWh/yr for electric tanks, and up to 9,195 kWh$_e$/yr for natural gas water heaters. Manitoba Hydro's estimate for its customer base (3,770 kWh/yr) is at the low end of this range, likely due to the smaller family size in their survey sample. Based on limited (and somewhat dated) research, it was concluded that about 65% of the residential DHW load can be described as a batch flow, i.e. in which the potable water and greywater flows do not occur at the same time. The remaining 35% can be categorized as a simultaneous flow load in which the two flows are concurrent. However, this distribution varies widely between houses.

## 8.2 TYPES OF RESIDENTIAL GREYWATER HEAT RECOVERY SYSTEMS

Residential GWHR systems can be broadly classified into four distinct types:

- Combined storage tank/heat exchanger type which uses thermal conduction and convection to transfer heat between the greywater and potable water
- Combined storage tank/heat pump type which uses a heat pump to facilitate the heat transfer process
- Non-storage type which does not use thermal storage but connects directly into the house's drain/waste/vent stack
- Point-of-use type which is incorporated directly into an end-use device, such as a shower, and consists of a heat exchanger but no thermal storage

The first two types of systems can recover heat from both batch and simultaneous flow loads whereas the last two can only recover appreciable energy from simultaneous flow loads.

## 8.3 BENEFITS

There are a number of benefits which a properly designed residential GWHR system can provide to a homeowner or to a utility which is supplying the energy for the DHW heater:

- Energy savings
- Increased First-Hour Rating of the tank
- Improved comfort due to slower temperature degradation at run-out
- Reduction of the coincident, peak demand
- Possible elimination of one tank in an otherwise dual-tank system

## 8.4 TECHNICAL OBSTACLES

There are a number of potential technical obstacles which residential GWHR systems have to overcome including:

- Controlling installed system costs
- Possible need for segregated plumbing
- Physical size, lost floor space and the need to be located below the greywater source(s)
- Maintenance requirements
- Possibility and perception of contamination
- Temperature control of the domestic hot water at the end-use

Of all these potential obstacles, controlling system costs and minimizing or eliminating maintenance requirements were judged as the most significant and which posed the greatest threat to adoption of GWHR technology.

## 8.5 OBSTACLES TO COMMERCIALIZATION OF THE TECHNOLOGY

Several obstacles stand in the way of large-scale commercialization of the technology. Although none are regarded as insurmountable, each will have to be addressed:

- Lack of market awareness
- Limited performance data
- Perceived cost effectiveness
- Health and safety concerns
- Possible opposition by building officials
- Absence of testing and product standards

## 8.6 CURRENT COMMERCIAL ACTIVITIES

Five firms were identified who are presently marketing residential GWHR systems or who are intending to enter the marketplace. One of these, an established manufacturer of hot water tanks, is currently in commercial production with a projected output of hundreds of units per year. Their first units were shipped last year. The remaining four firms are still attempting to bring their products into full production.

## 8.7 APPLICATIONS

Selection of the proper application is as important as the design of the type of GWHR product or system which is chosen for the application. Characteristics of a good application are:

- Expensive DHW energy source
- High DHW consumption
- Poor water heater efficiency
- Large family size
- Limited opportunity for hot water conservation

- Need for two DHW tanks
- Willingness of the family to adopt a new technology
- Applications where demand control is important
- Applications where multiple households use common greywater plumbing

## 8.8 MARKETING THE TECHNOLOGY

Many valuable lessons about marketing GWHR technology can be learned from initiatives like the R-2000 Program and from other products/industries with similar development histories (e.g. Heat Recovery Ventilators). To create consumer acceptance, they recognized that marketing of energy conservation products must emphasize the benefits which the product provides rather than their technical features. They also realized that promotion of the benefits must focus on the comfort, convenience and lifestyle advantages of the product (e.g. "more hot water at no extra cost") rather than on its economics - even though the economics may be attractive for many applications. It is critical that GWHR system marketing strategies not fall into the "payback trap" argument, in which decisions are evaluated on a simple cost recovery basis since most consumers do not make purchasing decisions using detailed economic analyses. The marketing plans developed for GWHR systems must recognize this fact and focus their efforts accordingly.

## 8.9 POTENTIAL MARKETS

Several potential markets were identified which could successfully be exploited by GWHR technology. The first is R-2000 houses, primarily because of the higher level of awareness about energy-related issues among their builders and homebuyers. While the R-2000 market is relatively small, it has a high profile. The second market is multi-unit residential buildings such as duplexes, condominiums and small apartments blocks, particularly those with dwelling units stacked vertically. Since several units often drain into the same DWV stack, greywater flows are larger and more frequent creating a better opportunity for heat recovery.

The third potential market for GWHR technology is electric utilities who could use these systems in their Demand Side Management programs or who wish to compete more aggressively with natural gas or oil for the hot water heating customer. The combination of a high efficiency, electric water heater and a GWHR system could, in some situations, be cost competitive, from a delivered-energy perspective, with natural gas systems due to the inherent efficiency of the electric tank/GWHR combination and the relatively low efficiency of combustion water heaters. The electric tank/GWHR combination could also compete very effectively against higher efficiency combustion water heaters because the latter tend to have significantly higher costs, relative to conventional tanks, with only modest improvements in performance (unless the most sophisticated, and expensive, type of tank is used).

The fourth potential market for residential GWHR systems is remote locations which have high energy costs, such as many sites in the Northwest and Yukon Territories. These areas have energy costs which are often several times those in southern Canada so the energy-saving capabilities of a residential GWHR system could be well used. However, reliability and the need for low-maintenance are very critical issues for mechanical equipment in these locations.

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